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COVER

Left: The wildfires of early 2003 left many shrub-dominated communities in the Australian Alps, bare. This area south of Mt Jim in north-eastern Victoria was dominated by *Kunzea muelleri* prior to the fire. One year after the fire the site was still largely bare.

Right: There has been no evidence of basal regeneration in *Podocarpus lawrencei* shrubs more than two years after the wildfire at Mt Blue Cow in Kosciuszko National Park. Dead stems have been aged up to 330 years old using annual ring countsat.

Photographer: Keith L. McDougall

Allan Cunningham

Allan Cunningham, botanist and explorer (1791–1839)

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Native riparian vegetation in Tasmania

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Abstract: Twenty-one riparian vascular plant communities are defined, mapped and described using presence/absence data from 460 sites from relatively unmodified stretches of rivers and streams on mainland Tasmania. The process of classification involved selection of groups of floristically distinct sites from a sorted table produced by a polythetic divisive process. The communities have strong geographic patterns. Many communities have a wide range of structural expression and/or dominants. Nearly half of the native vascular flora of Tasmania is present in the sites, including a large number of conservation-significant species, some of which are concentrated in riparian vegetation. In the drier, lowland parts of the State there are large areas with little or no native riparian vegetation remaining. Several of the communities that occur in this environment appear to be totally unreserved, while most of the communities from colder and more humid areas are represented within secure reserves.

***Cunninghamia* (2004) 8(4): 409–430**

Introduction

Riparian vegetation is thought to be of critical importance for the health of aquatic communities, and as a refugium for threatened species in the landscape. As elements of biodiversity, riparian vascular plant communities are also of importance in themselves. Surprisingly, there are relatively few studies of variation in riparian vegetation at even the large catchment scale, with the studies of Merry et al. (1981) on the River Wye in England, Curry and Slater (1986) on four Welsh catchments, and that of Wasklewicz (2001) on central Arizonan rivers seeming to exhaust examples in international journals. The grey literature is likely to be richer in examples (e.g. Jarman & Crowden 1978, Kirkpatrick & Glasby, 1981, Kirkpatrick & Harwood 1983, North et al. 1998, Bridle & Kirkpatrick 1998, Woolley 1999, Davidson & Gibbons 2001).

In Tasmania, most major vegetation types have been sampled on a statewide basis, communities differentiated, and their reservation status assessed (Kirkpatrick et al. 1995). Riparian vegetation has been the biggest gap; an unfortunate one given the extent of stream modification for energy production and the exponential taming of Tasmanian streams under the Water Development Plan of the Tasmanian Government (DPIWE 2001). Kirkpatrick et al. (1995) in their conspectus of the reservation status of Tasmanian plant communities attempted to use the geographically partial information on riparian vegetation (Duncan 1983, Jarman et al. 1984, Hughes 1987a, Harris & Kirkpatrick 1991, Askey-Doran 1993) to provide a typology and reservation assessment, with an inevitably unsatisfactory outcome.

In the present paper we develop a classification of riparian plant communities for mainland Tasmania and deduce the reservation status of these communities. We also provide information on the importance of Tasmanian riparian vegetation for the conservation of vascular plant species.

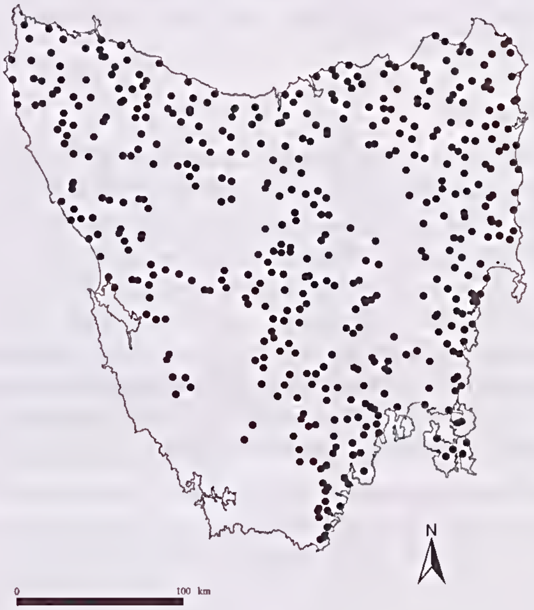


Fig. 1. Riparian vegetation survey sites.

Methods

Site selection

Relatively intact riparian vegetation in each of the 10 × 10 km national mapping grid squares in mainland Tasmania was sampled (Daley 2003). Four hundred and sixty riparian sites were surveyed. Vegetation was regarded as relatively intact if exotic plants constituted less than 20% of the estimated overlapping cover and the stream showed no obvious signs of physical modification in the immediate vicinity. It proved not possible to gain access to many of the grid squares in the wilderness areas of the west of the State (Fig. 1). However, sufficient samples were gained from these areas to be confident that the variation in their riparian vegetation was adequately covered. More significantly, no stands of native riparian vegetation that met the selection criteria could be found in 44 of the grids that were easily accessed. In 16 other grids that were easily accessed, it was possible that some isolated stands of riparian vegetation were present, but access to potential sites was not possible.

Data collection

Riparian vegetation was defined as that between the aquatic zone of the stream and the cessation of evidence of flood scouring or deposition. A list of vascular plant taxa (nomenclature according to Buchanan 1999) was obtained from this vegetation at each site, with searching for new taxa continuing along the stream on both sides until the nature of the orthogonal patterning, or type, of the vegetation changed, or no new taxa were evident. This plotless procedure aggregated vegetation zones in the relatively few sites where they clearly existed. Following the schema of Specht (1974), the structural types that occurred within this releve were recorded, as were the dominant taxa in each stratum. Taxa were regarded as codominant if they had about equal cover in the community.

Data analysis

A gigantic sorted table was produced using the polythetic divisive classificatory program, TWINSPAN (Hill 1979, Minchin 1990), on the taxon presence/absence data. The table was examined in detail to select groups of releves that: could be keyed out by combinations of the presences and absences of taxa; were relatively uniform within; and were constituted of at least 5 releves. Twenty-one such groups were selected from the table. Floristic similarities amongst groups were calculated using the Bray-Curtis measure on percentage frequency of species in groups.

The structural/dominance description of each community was derived from the structural/dominance descriptions of all sites within a community. The vegetation structure and dominant taxa that were common to the largest number of sites in a community were selected as the descriptors of the community. Affinity with previously described communities (those listed in Kirkpatrick et al. 1995, Wintle 2002) was calculated as the percentage of the number of frequently occurring species in common, divided by the mean number of species in the two lists (Bray-Curtis similarities). An affinity score of 50% or greater was taken to indicate close similarity between the newly described community and a previously listed or described community.

Reservation analysis

The land tenure of riparian reaches was determined. A distinction was made between secure reserves, protected by World Heritage status, or by the requirement for the approval of both houses of the Tasmanian parliament for revocation, and insecure reserves, which can be revoked by ministerial decision. Floristic communities have been regarded as well-reserved in Tasmania if they occur in at least two viable, and spatially well-separated areas within secure reserves (Kirkpatrick et al. 1995). This convention is followed herein. Poorly-reserved is defined as presence within a secure reserve, but failure to satisfy the above criteria. Unreserved constitutes absence from a secure reserve. Our analysis of reservation status is largely based on the sample of releves. However, general observations of particular communities within reserves have also been used, as have records from the literature, where the nature of the community is clear.

Results

The Tasmanian riparian vascular flora

A total of 857 native taxa and 89 exotic taxa were recorded from the releves. The number of native taxa per site ranged between 10 at Falls Rivulet in the Southern Ranges bioregion to 85 along the middle reaches of the Little Swanport River in the South East bioregion. A large proportion of the native riparian species are shrubs (31%) and herbs (27%). A high proportion of the State's species of native trees, shrubs and ferns were found in the releves (Table 1). The most common species are *Pomaderris apetala* and *Leptospermum lanigerum*. Only 8 species are found in more than half the sites and only 84 species in at least 10% of sites (Table 2). Of all native Tasmanian vascular plant species, only two species, *Gynatrix pulchella* and *Phebalium daviesii*, both exceedingly rare, are known to occur only in riparian zones (Table 3). There are, however, 76 vascular plant species that are found predominantly in riparian zones of Tasmania and therefore could be categorized as 'riparian' plants (Table 3). Nearly 30% of these riparian plants are listed as threatened. While not all Tasmania's riparian plants were detected during the survey, there were forty-six species listed under the Tasmanian *Threatened Species Protection Act* 1995 (as of 2002).

Table 1. The number and proportion of observed native taxa in the riparian zone in life-form classes, and as a proportion of life-form classes in Tasmania

Life-form	No. of taxa	% of total	% of Tasmanian species
Trees	62	7	58
Shrubs	265	31	51
Graminoids	170	20	38
Herbs	231	27	36
Grasses	61	7	37
Ferns	68	8	54

Table 2. Native vascular plant taxa found at 10% or more riparian sites.

Common riparian species	% freq	Lifeform
Pomaderris apetala	69	tree/shrub
Bursaria spinosa	22	shrub
Leptospermum lanigerum	65	tree/shrub
Histiopteris incisa	22	fern
Acaena novae-zelandiae	62	herb
Monotoca glauca	21	shrub
Acacia dealbata	61	tree
Beyeria viscosa	21	shrub
Blechnum nudum	60	fern
Blechnum minus	21	fern

Pteridium esculentum	58	fern
Nematolepis squamea	20	shrub
Acacia melanoxylon	58	tree
Exocarpos cupressiformis	20	shrub
Coprosma quadrifida	54	shrub
Melaleuca squarrosa	20	shrub
Carex appressa	46	sedge
Juncus pauciflorus	20	rush
Gahnia grandis	44	sedge
Eucalyptus ovata	19	tree
Polystichum proliferum	42	fern
Lomatia tinctoria	19	shrub
Dicksonia antarctica	41	fern
Poa spp.	19	grasses
Cassinia aculeata	40	shrub
Eucryphia lucida	18	tree
Blechnum wattsii	38	fern
Epacris impressa	18	shrub
Eucalyptus viminalis	38	tree
Gleichenia microphylla	17	fern
Lomandra longifolia	38	graminoid
Notelaea ligustrina	16	tree
Acacia verticillata	37	tree/shrub
Microsorum pustulatum	16	fern
Oxalis perennans	34	herb
Hypericum japonicum	16	herb
Viola hederacea	34	herb
Lepidosperma laterale	15	sedge
Pimelea drupacea	34	shrub
Euchiton spp.	15	herbs
Nothofagus cunninghamii	33	tree
Sticherus tener	15	fern
Agrostis spp.	33	grasses
Anopterus glandulosus	15	shrub
Hydrocotyle hirta	33	herb
Eucalyptus delegatensis	15	tree
Eucalyptus obliqua	32	tree
Schoenus spp.	15	sedges
Poa labillardierei	32	grass
Eucalyptus regnans	15	tree
Leptospermum scoparium	31	tree/shrub
Isolepis spp.	15	sedges
Acacia mucronata	30	shrub
Olearia argophylla	14	shrub
Eucalyptus amygdalina	30	tree
Hypolepis rugosula	14	fern
Poaceae spp.	29	grasses
Juncus astreptus	14	rush
Clematis aristata	27	climber
Ozothamnus ferrugineus	14	shrub
Olearia lirata	25	shrub
Zieria arborescens	14	shrub
Tasmannia lanceolata	25	shrub
Allocasuarina littoralis	13	shrub
Juncus spp.	25	rushes
Schoenus maschalinus	13	sedge
Pultenaea juniperina	25	shrub
Melaleuca ericifolia	12	tree/shrub
Gonocarpus teucrioides	24	herb
Aristotelia peduncularis	12	shrub
Dianella tasmanica	24	lily
Baloskion tetraphyllum	12	rush
Banksia marginata	24	tree/shrub
Eucalyptus globulus	12	tree
Geranium potentilloides	23	herb
Cyathodes juniperina	11	shrub
Lepidosperma ensiforme	23	sedge
Senecio hispidulus	11	herb
Prostanthera lasianthos	23	shrub
Billardiera longiflora	10	climber
Pittosporum bicolor	23	shrub
Juncus australis	10	rush
Atherosperma moschatum	23	tree
Lepidosperma elatius	10	sedge

Table 3. Native species that show a strong preference for riparian vegetation, their lifeform, Tasmanian endemism and conservation status in Tasmania (under the Tasmanian *Threatened Species Protection Act* 1995).

Species	Lifeform	Endemic (e) Rare (r) Vulnerable (v) Endangered (en)
Acacia axillaris	shrub	e; v
Acacia sp.	shrub	e
Acradenia frankliniae	tree	e
Alternanthera denticulata	herb	en
Amphibromus neesii	grass	
Asperula charophyton	herb	en
Asterotrichion discolor	shrub	e
Barbarea australis	herb	e; en
Bertya rosmarinifolia	shrub	v
Blechnum cartilagineum	fern	
Blechnum chambersii	fern	
Callistemon viridiflorus	shrub	e
Callitris oblonga	tree	e; v
Carex appressa	sedge	
Carex gaudichaudiana	sedge	
Carex polyantha	sedge	
Centipeda cunninghamii	herb	r
Discaria pubescens	shrub	
Eleocharis acuta	sedge	
Eleocharis gracilis	sedge	
Eleocharis pusilla	sedge	
Epacris apsleyensis	shrub	e; en
Epacris exserta	shrub	e; v
Epacris grandis	shrub	e; v
Epacris mucronulata	shrub	e
Eucalyptus ovata	tree	
Gleichenia dicarpa	fern	
Gleichenia microphylla	fern	
Gratiola nana	herb	
Gratiola peruviana	herb	
Gratiola pubescens	herb	
Grevillea australis var. *australis*	shrub	
Grevillea australis var. *brevifolia*	shrub	e
Grevillea australis var. *erecta*	shrub	e
Grevillea australis var. *linearifolia*	shrub	e; r
Grevillea australis var. *planifolia*	shrub	e; r
Grevillea australis var. *subulata*	shrub	e
Grevillea australis var. *tenuifolia*	shrub	e
Gunnera cordifolia	herb	e
Gynatrix pulchella	shrub	r
Hydrocotyle comocarpa	herb	r
Hydrocotyle pterocarpa	herb	
Isolepis fluitans	sedge	
Isolepis inundata	sedge	
Isolepis producta	sedge	
Isotoma fluviatilis	herb	
Juncus procerus	rush	
Lagarostrobos franklinii	tree	e
Leptospermum riparium	shrub	e
Lycopus australis	herb	en
Lythrum salicaria	herb	
Mazus pumilio	herb	
Micrantheum hexandrum	shrub	
Milligania longifolia	lily	e; r
Mimulus repens	herb	

Olearia obcordata	shrub	e
Oreomyrrhis gunnii	herb	e
Ourisia integrifolia	herb	e
Persicaria decipiens	herb	v
Phebalium daviesii	shrub	e; en
Plantago daltonii	herb	e
Pomaderris elachophylla	shrub	v
Pomaderris phylicifolia	shrub	r
Pultenaea selaginoides	shrub	e; v
Ranunculus amphitrichus	herb	r
Richea gunnii	shrub	e
Rorippa dictyosperma	herb	
Rumex bidens	herb	r
Rumex brownii	herb	
Scaevola aemula	herb	
Scaevola hookeri	herb	
Schoenus fluitans	sedge	
Spyridium gunnii	shrub	e
Spyridium lawrencei	shrub	e; v
Typha domingensis	grass	
Uncinia riparia	sedge	

The 89 exotic plant species recorded during the survey represent around 12% of introduced vascular plants in Tasmania. *Ulex europaeus* (Gorse), *Rubus fruticosus* (Blackberry), *Salix fragilis* (Crack willow) and *Crataegus monogyna* (Hawthorn) thrive in the riparian zone in Tasmania. While these four prominent shrubs are prolific and form extensive stands across much of the developed riparian landscape, the large number of exotic species observed to be invading native stands of riparian vegetation is of concern.

Community characteristics and their reservation status

Descriptions of the 21 riparian native floristic communities including the defining floristic characteristics based on the TWINSPAN sorted table, structural characteristics and reservation status follow. Taxa occurring in 30% or more of sites within a community are listed in the Appendix.

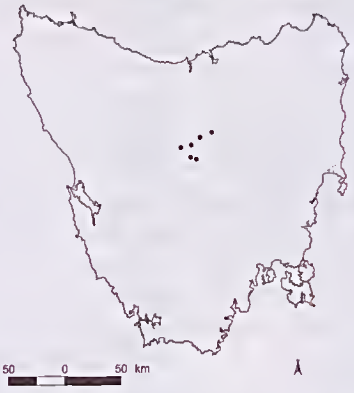


Fig. 2a. Community 1 *Orites acicularis – Baeckea gunniana – Richea acerosa – Hierochloe redolens – Poa costiniana* grassy heath.

Community 1: *Orites acicularis – Baeckea gunniana – Richea acerosa – Hierochloe redolens – Poa costiniana* grassy heath

Sample sites: 6 Mean no. species: 48.7 (sd 16.0)

Defining floristic assemblage: *Baeckea gunniana, Richea acerosa, Hierochloe redolens, Agrostis* spp., *Ranunculus triplodontus* and *Epacris serpyllifolia.*

Location: Central Highlands at altitudes of 1000 m or higher, in the catchments of the River Ouse, upper River Derwent and a watercourse that drains into Great Lake (Fig. 2a).

Structural characteristics: There are two distinctive structural variants within this community: (a) heath; and (b) open-heath over closed-grassland.

Tallest stratum: In the heath variant, *Orites acicularis, Baeckea gunniana* and *Leptospermum rupestre* are dominant and form closed thickets. Open-heath is much shorter, rarely exceeding 0.5 m in height. *Richea acerosa* is the dominant woody shrub in the tallest stratum of this variant with a covering of less than 50%.

Ground stratum: In the heath variant, alpine grasses, sedges, rushes and a diverse array of herbs usually dominate. There is a dense cover of tussock grasses, mainly *Poa costiniana* and *Austrodanthonia* species underlying the open-heath variant.

Adjacent communities: Grassy–sedgey heath dominated by *Ozothamnus, Leptospermum* or *Richea* species and *Eucalyptus coccifera* heathy open-forest.

Closely related riparian floristic community: Community 3.

Affinity with other listed or described community: None.

Reservation status: Well-reserved in the Central Plateau Conservation Area within the World Heritage Area and the Cradle Mountain-Lake St Clair National Park.

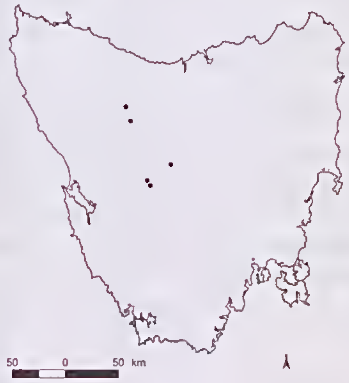


Fig. 2b. Community 2 *Eucalyptus* open-forest over *Baeckea gunniana – Gleichenia alpina – Rubus gunnianus* sedgey–ferny closed-heath.

Community 2: *Eucalyptus* open-forest over *Baeckea gunniana – Gleichenia alpina – Rubus gunnianus* sedgey–ferny closed-heath

Sample sites: 5 Mean no. species: 43.2 (sd 14.7)

Defining floristic assemblage: *Baeckea gunniana, Gleichenia alpina, Oxylobium ellipticum, Rubus gunnianus, Gymnoschoenus sphaerocephalus, Lomatia polymorpha* and *Allocasuarina zephyrea.*

Locations: Central Highlands at altitudes between 700 m and 1000 m, alongside headwater and middle-order streams of the River Forth, upper River Derwent and Pieman River catchments (Fig. 2b).

Structural characteristics: There are two distinctive structural/dominance variants: (a) *Eucalyptus* open-forest with a heathy understorey; and (b) *Hakea–Leptospermum* ferny–sedgey–grassy heath.

Tallest stratum: In the heathy open-forest, *Eucalyptus delegatensis* or *Eucalyptus pauciflora* occur as dominants with *Eucalyptus rodwayi, Eucalyptus dalrympleana* and *Eucalyptus gunnii* occasionally present. In the treeless heath community, *Baeckea gunniana, Leptospermum rupestre, Leptospermum nitidum, Leptospermum lanigerum* and *Hakea epiglottis* are the dominant shrubs.

Middle stratum: Amongst a variety of other shrubs, *Leptospermum lanigerum* and *Melaleuca squamea* are dominant in the heathy open-forest variant. The second stratum of this community is also characterised by a diverse range of heathy shrubs with a cover of between 76% and 100% and a height between 0.5 m and 1 m. The dominant species recorded in the treeless heath variant are *Nematolepis squamea* subsp. *retusa*, *Hakea lissosperma*, *Melaleuca squamea*, *Ozothamnus hookeri*, *Leptospermum lanigerum*, *Carex gaudichaudiana* and *Baeckea gunniana*.

Ground stratum: Shrubs, of which *Cyathodes parvifolia* and *Bauera rubioides* are the most common, dominate the heathy open-forest variant. Underlying the shrubs sparse coverings of herbs and a variety of graminoids, including rushes, cord rushes and sedges and/or a variety of ferns can also be found. In the treeless heath community where dominant species are discernible, these are usually *Bauera rubioides*, *Poa* species, *Gleichenia alpina* and *Cyathodes parvifolia*.

Adjacent communities: *Eucalyptus delegatensis*, *Eucalyptus pauciflora*, *Eucalyptus rodwayi*, and *Eucalyptus coccifera* heathy woodlands, buttongrass plains and, at one site, a *Poa* tussock grassland.

Closely related riparian floristic community: Community 3.

Affinity with other listed or described community: None.

Reservation status: Well-reserved. The community was sampled in the Cradle Mountain-Lake St Clair National Park, and an insecure reserve, the Vale of Belvoir Conservation Area. It occurs widely in the Cradle Mountain-Lake St Clair National Park

Community 3 along the Shannon River, *Eucalyptus* woodland over *Leptospermum lanigerum* sedgey heath.

Community 3: *Eucalyptus gunnii* woodland or open-forest over herby, grassy, sedgey *Leptospermum lanigerum* open-heath and closed-scrub

Sample sites: 11 Mean no. species: 41.8 (sd 15.1)

Defining floristic assemblage: *Leptospermum lanigerum*, *Eucalyptus gunnii*, *Acaena novae-zelandiae*, *Cyathodes parvifolia* and *Carex gaudichaudiana*

Locations: Central Highlands and the Southern Ranges bioregions at altitudes between 650 m and 1050 m. This community occurs mostly in the upper reaches of the Arthur River, River Clyde, River Ouse, Pieman River and upper River Derwent catchments and along watercourses that drain to the north coast and to Great Lake (Fig. 2c).

Structural characteristics: Structural variations in this community result primarily from variation in cover within each of the strata. The ground stratum of this community displays the greatest variation in species composition and cover. This is one of the communities where evidence of the interaction of native animals is abundant, as marsupial lawns occur in over half the sites.

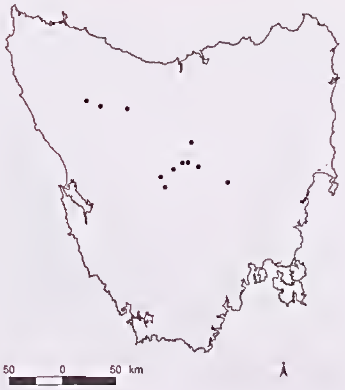


Fig. 2c. Community 3 *Eucalyptus gunnii* woodland or open-forest over herby, grassy, sedgey *Leptospermum lanigerum* open-heath and closed-scrub.

Tallest stratum: *Eucalyptus gunnii* is the most common dominant but *Eucalyptus pauciflora*, *Eucalyptus rodwayi*, *Eucalyptus coccifera*, and *Eucalyptus dalrympleana* may also be present or dominant.

Second stratum: *Leptospermum lanigerum* is the most common dominant. *Banksia marginata*, *Callistemon viridiflorus* and *Hakea epiglottis* may also be present as co-dominants. *Tasmannia lanceolata*, *Hakea microcarpa*, *Coprosma nitida*, *Bedfordia linearis*, *Grevillea australis* and *Almaleea subumbellata* are also frequently found.

Ground stratum: The dominant species include *Carex gaudichaudiana*, *Poa labillardierei*, *Bauera rubioides*, *Cyathodes parvifolia*, *Leptospermum lanigerum* and *Baloskion australe*, although there is sometimes no clear dominant because of the diverse combinations of herbs, *Poa* and Cyperaceae species.

Adjacent communities: Buttongrass plains and heathy and scrubby *Eucalyptus* woodland and open-forest.

Closely related riparian floristic community: Community 12.

Affinity with other listed or described community: None.

Reservation status: Well-reserved. The community was sampled in only one reserve, the insecure Wentworth Creek Forest Reserve. However, it has been observed in the south of the Cradle Mountain-Lake St Clair National Park, and in the Walls of Jerusalem National Park.

Community 4: *Melaleuca ericifolia – Lomandra longifolia – Juncus kraussii* estuarine forest and scrub

Sample sites: 14 Mean no. species: 32.5 (sd 8.7)

Defining floristic assemblage: *Juncus kraussii*, *Samolus repens*, *Gahnia filum*, *Acacia sophorae*, *Selliera radicans*, *Schoenus nitens*, *Bursaria spinosa*, *Exocarpos cupressiformis*, *Leptinella longipes*, *Phragmites australis*, *Leucopogon parviflorus* and *Rhagodia candolleana* (mostly salt-tolerant species).

Locations: Estuarine reaches of watercourses predominantly along the north coast of Tasmania but also at the estuary of Arthur River in the northwest and Catamaran River in the south (Fig. 2d).

Structural characteristics: The most common structural/dominance type within this community is *Eucalyptus* woodland or open-forest over a sedgey, grassy or ferny *Melaleuca* closed-scrub. *Melaleuca* sedgey–herby closed-forests and various sedgey, scrubby, ferny, herby or grassy open-scrub structures also occur. *Melaleuca ericifolia* is present at nearly all sites and is dominant in one-third of the sites. Where *Eucalyptus* species are present in the tallest stratum, *Melaleuca ericifolia* is frequently dominant in the middle stratum. The ground stratum displays greatest variability in its composition, frequently including a variety of grasses, sedges, rushes, ferns and herbs.

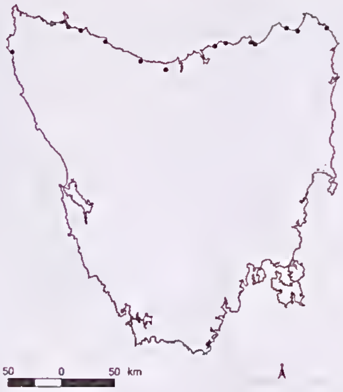


Fig. 2d. Community 4 *Melaleuca ericifolia – Lomandra longifolia – Juncus kraussii* estuarine forest and scrub.

Tallest stratum: *Melaleuca ericifolia* is the most frequently occurring dominant species although *Eucalyptus amygdalina, Eucalyptus ovata, Eucalyptus obliqua, Eucalyptus pauciflora, Melaleuca squarrosa* and *Acacia sophorae* also occur as dominants. *Banksia marginata, Leptospermum scoparium* and *Pomaderris apetala* are frequently found as co-dominants.

Middle stratum: As well as *Melaleuca ericifolia, Melaleuca squarrosa, Leucopogon parviflorus, Leptospermum scoparium, Allocasuarina littoralis, Rhagodia candolleana* and *Acacia sophorae* are also amongst the shrubs that dominate. At some sites within this community, graminoids are dominant, *Lepidosperma elatius, Lepidosperma ensiforme*, and *Gahnia filum* being the most common. The grass, *Phragmites australis*, was also recorded as an infrequent dominant species in this stratum.

Ground stratum: Amongst the dominants in this stratum are *Juncus kraussii, Schoenus nitens, Lomandra longifolia, Poa labillardierei, Austrostipa stipoides, Distichlis distichophylla, Lepidosperma ensiforme, Leptocarpus tenax, Pteridium esculentum* and *Blechnum nudum*.

Adjacent communities: Coastal scrub and scrubby, sedgey or ferny *Eucalyptus* woodland and open-forest.

Closely related riparian floristic community: Community 5.

Affinity with other listed or described community: None.

Reservation status: Well-reserved. This community was sampled in Mt William National Park, has been observed in the Narawntapu National Park and the South West National Park, and also occurs in a large number of insecure reserves.

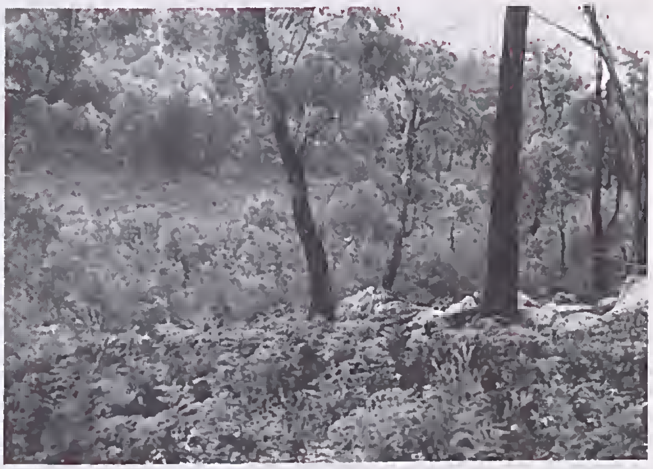
Community 5: *Melaleuca squarrosa – Leptospermum lanigerum* heathy–ferny–sedgey closed-scrub

Sample sites: 35 Mean no. species: 33.8 (sd 8.7)

Defining floristic assemblage: *Pteridium esculentum, Melaleuca squarrosa, Leptospermum lanigerum, Gahnia grandis, Blechnum nudum, Dicksonia antarctica, Blechnum minus, Polystichum proliferum, Blechnum wattsii, Gleichenia microphylla, Gleichenia dicarpa* and *Hydrocotyle hirta*.

Locations: Widespread at altitudes up to 400 m (Fig. 2e) and found from headwaters to estuaries.

Structural characteristics: There are three structural/dominance variants: (a) *Eucalyptus, Acacia, Melaleuca* or *Leptospermum* forest with an understorey of ferns and/or sedges; (b) *Eucalyptus, Acacia, Melaleuca, Leptospermum* or *Banksia* woodland over ferny–sedgey–heathy closed-scrub; and (c) *Eucalyptus, Acacia or Leptospermum* woodland over ferny-sedgey-grassy heath. The second variant is the most common type. Small shrubs, sedges and/or ferns all occur as dominants in this community.



Community 5 along Bosses Creek, *Eucalyptus* woodland over closed-heath.

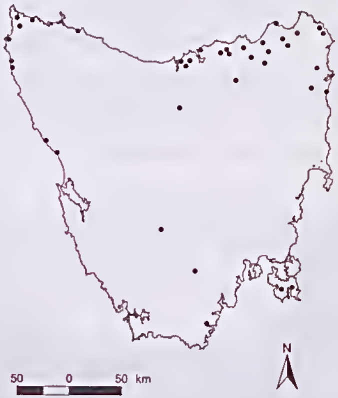


Fig. 2e. Community 5 *Melaleuca squarrosa – Leptospermum lanigerum* heathy–ferny–sedgey closed scrub.

Tallest stratum: *Eucalyptus, Acacia, Melaleuca, Leptospermum* or *Banksia* species are found as dominants, with the most common being *Eucalyptus obliqua, Eucalyptus ovata, Eucalyptus nitida, Eucalyptus amygdalina, Acacia melanoxylon* and *Leptospermum lanigerum*. *Acacia melanoxylon* and *Leptospermum lanigerum* are common dominants in the closed-forest variants of this community.

Middle stratum: Shrubs, most commonly *Melaleuca squarrosa, Pomaderris apetala, Melaleuca ericifolia* and *Leptospermum lanigerum* are the most frequently occurring dominants.

Ground stratum: Where shrubs are dominant, *Bauera rubioides, Kunzea ambigua, Leptospermum lanigerum, Leptospermum scoparium, Melaleuca squarrosa* or *Bossiaea cordigera* were the dominant species. The dominant sedges and graminoids are *Lepidosperma filiforme, Lepidosperma laterale, Lepidosperma longitudinale, Lepidosperma ensiforme, Schoenus nitens, Carex appressa, Gahnia sieberiana* and *Empodisma minus*. Where ferns are dominant, *Gleichenia dicarpa, Gleichenia microphylla, Pteridium esculentum, Blechnum nudum* and *Todea barbara* were the most common.

Adjacent communities: *Eucalyptus* and *Melaleuca* scrubby, heathy or sedgey woodland and open-forest, buttongrass and *Xanthorrhoea* sedgelands.

Closely related riparian floristic community: Community 4.

Affinity with other listed or described community: This community has an affinity (53%) with *Asterotrichion discolor – Pteridium esculentum – Blechnum nudum – Lepidosperma ensiforme* fernland (Wintle 2002).

Reservation status: Well-reserved. This community was sampled in the Southwest and Mt William National Parks, and also occurs in a number of insecure reserves.

Community 6 along St Pauls River, *Eucalyptus* woodland over scrubby sedgeland.

Community 6: *Eucalyptus* woodland over *Hakea microcarpa – Poa labillardierei – Lomandra longifolia* grassy–sedgey scrub

Sample sites: 9 Mean no. species: 48 (sd 19.0)

Defining floristic assemblage: *Hakea microcarpa, Epacris gunnii, Lepidosperma inops, Hibbertia prostrata, Lagenifera stipitata, Hibbertia riparia, Epacris apsleyensis, Grevillea australis, Baumea juncea, Baeckea ramosissima* and *Astroloma humifusum.*

Locations: At altitudes from sea level to 320 m in the catchments of the Apsley, Little Swanport, St Pauls, Swan, Wye and Macquarie Rivers and along an unnamed minor watercourse at Dodges Ferry (Fig. 2f).

Structural characteristics: There are two main variants of this community: (a) *Eucalyptus* woodland over sedgey and/or grassy scrub; and (b) *Eucalyptus* woodland over scrubby and/or grassy sedgeland. *Eucalyptus* cover in this community is always less than 25% and ferns are rarely present.

Tallest stratum: *Eucalyptus viminalis* is by far the most common dominant species but *Eucalyptus amygdalina, Eucalyptus ovata, Eucalyptus rodwayi, Eucalyptus pulchella* and *Eucalyptus tenuiramis* are occasional dominants.

Middle stratum: *Leptospermum lanigerum* is the most common dominant species with *Melaleuca squamea, Acacia mucronata, Acacia verticillata, Acacia melanoxylon, Leptospermum scoparium, Callitris oblonga, Allocasuarina littoralis* and *Allocasuarina monilifera* occurring infrequently as dominants. Also common are *Hakea microcarpa, Hibbertia riparia, Micrantheum hexandrum, Pomaderris apetala* and *Bursaria spinosa.*

Ground stratum: This stratum is variously dominated by *Poa* species, *Lepidosperma inops. Lepidosperma laterale, Baumea juncea, Leptospermum lanigerum, Acacia mucronata* and *Baeckea ramosissima.* Also common are *Themeda triandra, Carex appressa, Epacris gunnii, Grevillea australis, Astroloma humifusum* and *Juncus* species.

Adjacent communities: Grassy–heathy–sedgey–scrubby *Eucalyptus* woodland and open-forest.

Closely related riparian floristic community: Community 7.

Affinity with other listed or described community: None.

Reservation status: Poorly-reserved. It was sampled in the secure Douglas-Apsley National Park, and insecure river reserves along the Little Swanport River, the St Pauls River at Royal George, and the Swan River Forest Reserve.

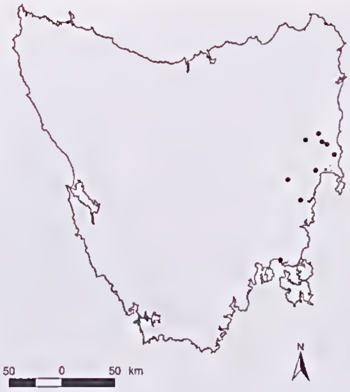
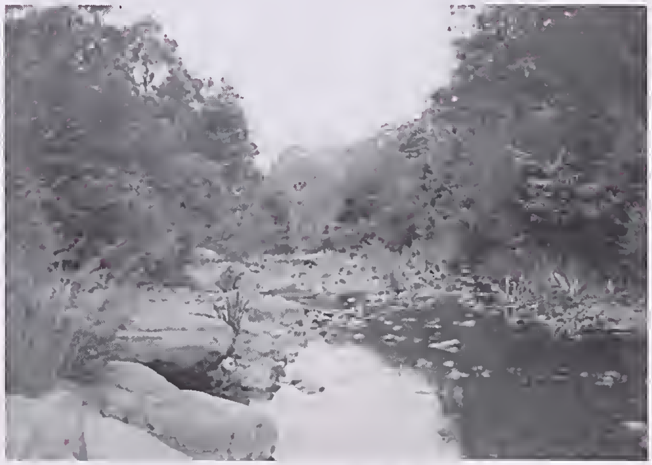


Fig. 2f. Community 6 *Eucalyptus* woodland over *Hakea microcarpa – Poa labillardierei – Lomandra longifolia* grassy–sedgey scrub.



Community 7 along the Buxton River, *Eucalyptus* woodland over grassy–sedgey closed-scrub.

Community 7: *Eucalyptus viminalis – Eucalyptus globulus – Eucalyptus obliqua – Eucalyptus amygdalina* woodland over *Beyeria viscosa – Exocarpos cupressiformis* sedgey-grassy, ferny or heathy closed-scrub

Sample sites: 58 Mean no. species: 35.2 (sd 10.8)

Defining floristic assemblage: *Eucalyptus globulus, Acacia melanoxylon, Allocasuarina littoralis, Bedfordia salicina, Cassinia aculeata, Beyeria viscosa, Epacris impressa, Lepidosperma laterale* and *Pteridium esculentum.*

Locations: Mainly in eastern Tasmania at altitudes from sea level to 380 m (Fig. 2g) and includes rocky estuarine sites.

Structural characteristics: The most common structural/dominance types in this community in order of frequency are: *Eucalyptus* woodland over sedgey–grassy open or closed-scrub; *Eucalyptus* woodland over sedgey open or closed-scrub; *Eucalyptus* woodland over sedgey–ferny open or closed-scrub; and *Eucalyptus* woodland over heathy closed-scrub.

Tallest stratum: The most common dominant species are *Eucalyptus viminalis, Eucalyptus obliqua, Eucalyptus globulus* and *Eucalyptus amygdalina.* At the sites where no tall *Eucalyptus* or *Acacia* species were present, *Dodonaea viscosa, Acacia verticillata* and *Leptospermum lanigerum* were recorded as the dominant species.

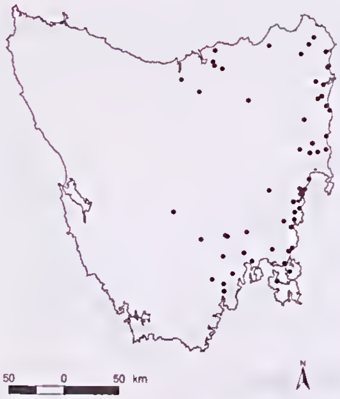


Fig. 2g. Community 7 *Eucalyptus viminalis – E. globulus – E. obliqua – E. amygdalina* woodland over *Beyeria viscosa – Exocarpos cupressiformis* sedgey–grassy, ferny or heathy closed-scrub.

Middle stratum: *Leptospermum lanigerum, Pomaderris apetala, Acacia mucronata, Acacia dealbata, Acacia melanoxylon, Acacia verticillata, Melaleuca ericifolia, Beyeria viscosa, Banksia marginata, Bursaria spinosa* and *Allocasuarina littoralis. Leptospermum lanigerum, Pomaderris apetala, Acacia mucronata, Acacia dealbata, Acacia melanoxylon, Acacia verticillata, Melaleuca ericifolia, Beyeria viscosa, Banksia marginata, Bursaria spinosa* and *Allocasuarina littoralis* were all recorded as dominant in this stratum.

Ground stratum: The most frequently occurring dominants in this stratum are *Leptospermum lanigerum, Leptospermum scoparium, Baeckea ramosissima, Lomandra longifolia, Lepidosperma laterale, Lepidosperma ensiforme* and *Carex appressa.*

Adjacent communities: *Eucalyptus* scrubby, sedgey, ferny, grassy, heathy woodland, or heathy open-forest.

Closely related riparian floristic community: Community 10.

Affinity with other listed or described community: This community has affinities with *Eucalyptus viminalis – Pomaderris apetala – Leptospermum lanigerum – Wahlenbergia* spp. shrubby open-forest (59%), *Eucalyptus amygdalina – Lomandra longifolia – Juncus* spp. *– Geranium potentilloides* sedgey woodland (56%) and *Crataegus monogyna – Rosa rubiginosa – Poa labillardierei – Dactylis glomerata* agricultural grassy woodland (52%) (Wintle 2002).

Reservation status: Poorly-reserved. The community occurs in the Mt Pearson State Reserve, and the following insecure reserves: Ansons River Reserve, Cameron Recreation Reserve, Swan River Forest Reserve.

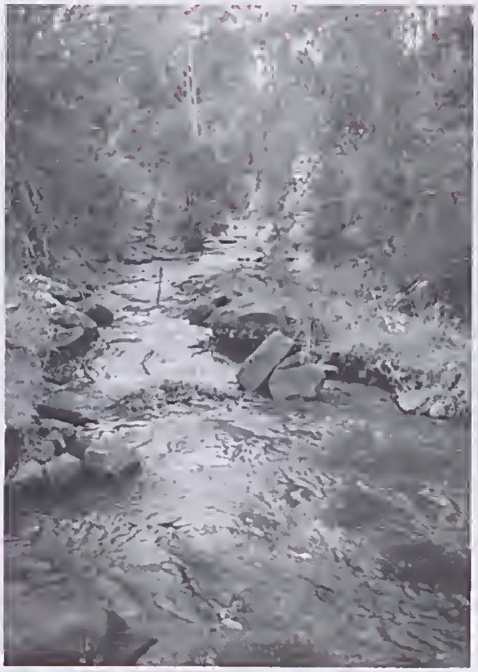
Community 8: *Eucalyptus obliqua – Eucalyptus regnans* woodland over *Acacia – Pomaderris* ferny–sedgey–grassy closed-scrub

Sample sites: 43 Mean no. species: 36.4 (sd 8.9)

Defining floristic assemblage: *Acacia dealbata, Acacia mucronata, Eucalyptus obliqua, Eucalyptus regnans, Eucalyptus delegatensis, Pomaderris apetala, Coprosma quadrifida, Cassinia aculeata, Acacia verniciflua, Acacia verticillata, Prostanthera lasianthos, Bedfordia salicina, Olearia lirata, Olearia viscosa, Notelaea ligustrina, Callistemon pallidus, Hypericum japonicum, Senecio* spp., *Lomatia tinctoria, Lepidosperma ensiforme, Hypolepis rugosula, Histiopteris incisa, Blechnum fluviatale, Juncus australe* and *Ehrharta stipoides.*

Locations: Predominantly in the east at altitudes from 20 m to 740 m (Fig. 2h).

Structural characteristics: There are two frequently occurring structural/dominance forms in this community: (a) *Eucalyptus* woodland over sedgey, ferny, grassy or heathy closed-scrub; and (b) *Acacia* or *Pomaderris* woodland over ferny, sedgey and/or heathy closed-scrub. This community exhibits high species diversity and cover in the middle and ground strata.



Community 8 at Crabtree Rivulet, *Eucalyptus obliqua/E. regnans* woodland over *Leptospermum lanigerum* grassy open-scrub.

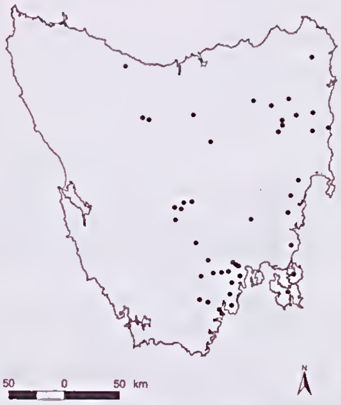


Fig. 2h. Community 8 *Eucalyptus obliqua – E. regnans* woodland over *Acacia – Pomaderris* ferny–sedgey–grassy closed-scrub.

Tallest stratum: The most frequently dominant eucalypts in this community are *Eucalyptus delegatensis, Eucalyptus viminalis,* and *Eucalyptus regnans,* although *Eucalyptus dalrympleana, Eucalyptus amygdalina, Eucalyptus ovata, Eucalyptus globulus* and *Eucalyptus sieberi* also occur as infrequent dominants. *Acacia dealbata and Pomaderris apetala* are the most frequently occurring dominant species where *Eucalyptus* species are either not present or very sparse.

Middle stratum: *Pomaderris apetala, Leptospermum lanigerum* and *Acacia dealbata* are the most common dominant species in the second stratum. Also occurring as infrequent dominants are *Bedfordia salicina, Ozothamnus thyrsoideus, Olearia argophylla, Olearia lirata, Allocasuarina littoralis, Beyeria viscosa, Acacia melanoxylon, Acacia mucronata, Acacia verniciflua, Acacia verticillata, Leptospermum riparium, Leptospermum scoparium, Pomaderris elliptica, Coprosma quadrifida, Zieria arborescens, Prostanthera lasianthos, Asterotrichion discolor, Micrantheum hexandrum* and *Melaleuca squarrosa.*

Ground stratum: Where a clear dominant species is discernible, shrubs, ferns, sedges and grasses are variably dominant. *Blechnum nudum* is the most frequent dominant species. Also occurring as infrequent dominant species are *Leptospermum lanigerum*, *Beyeria viscosa*, *Bauera rubioides*, *Prostanthera lasianthos*, *Carex appressa*, *Lepidosperma elatius*, *Lepidosperma laterale*, *Lepidosperma ensiforme*, *Lomandra longifolia*, *Blechnum wattsii*, *Blechnum minus*, *Dicksonia antarctica*, *Gleichenia microphylla*, *Polystichum proliferum* and *Poa labillardierei*.

Adjacent communities: *Eucalyptus* open-forest and woodland that may be scrubby, shrubby, sedgey, ferny, grassy or heathy.

Closely related riparian floristic community: Community 9.

Affinity with other listed or described community: *Eucalyptus obliqua – Olearia lirata – Pultenaea juniperina* wet sclerophyll forest (52%), *Eucalyptus regnans – Eucalyptus obliqua – Pomaderris apetala – Olearia lirata wet sclerophyll forest* (60%), *Eucalyptus delegatensis – Eucalyptus viminalis – Acacia melanoxylon* wet sclerophyll forest (55%); *Eucalyptus globulus – Acacia dealbata – Cassinia aculeata – Acacia melanoxylon wet sclerophyll forest* (52%), *Eucalyptus ovata – Acacia dealbata – Pomaderris apetala* wet sclerophyll forest (52%), *Eucalyptus regnans – Acacia dealbata – Pomaderris apetala* wet sclerophyll forest (52%), *Eucalyptus sieberi – Olearia argophylla – Coprosma quadrifida* wet sclerophyll forest (50%) (Kirkpatrick et al. 1995), and *Pomaderris apetala – Olearia argophylla – Coprosma quadrifida – Hymenophyllum* spp. open-forest (Wintle 2002).

Reservation status: Unreserved. The community is known from no secure reserves, but was sampled in the following insecure reserves: Weavers Creek Forest Reserve; Kenmere Creek Forest Reserve; Castle Cary Recreation Reserve; and may also occur in the Mountain Creek Conservation Area.

Community 9: *Eucalyptus viminalis – Eucalyptus ovata – Eucalyptus obliqua – Acacia dealbata – Acacia melanoxylon* woodland over sedgey-ferny scrub

Sample sites: 33 Mean no. species: 41.1 (sd 9.5)

Defining floristic assemblage: There is no species that is present at all sites in this community. However, it is characterized by the presences of most of *Eucalyptus ovata*, *Eucalyptus delegatensis*, *Acacia melanoxylon*, *Acacia verticillata*, *Acacia dealbata*, *Melaleuca ericifolia*, *Pittosporum bicolor*, *Exocarpos cupressiformis*, *Ozothamnus ferrugineus*, *Bursaria spinosa*, *Microlaena hexandrum*, *Correa lawrenceana*, *Tasmannia lanceolata*, *Senecio hispidulus*, *Blechnum minus* and *Rubus parvifolius*.

Locations: Mainly in the north at altitudes between 10 m and 540 m (Fig. 2i).

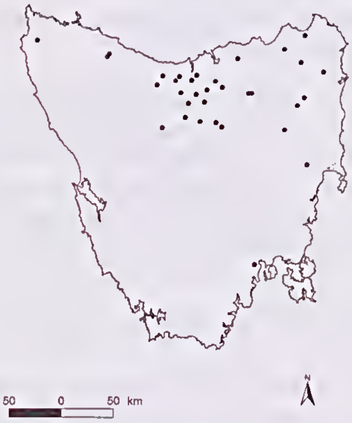
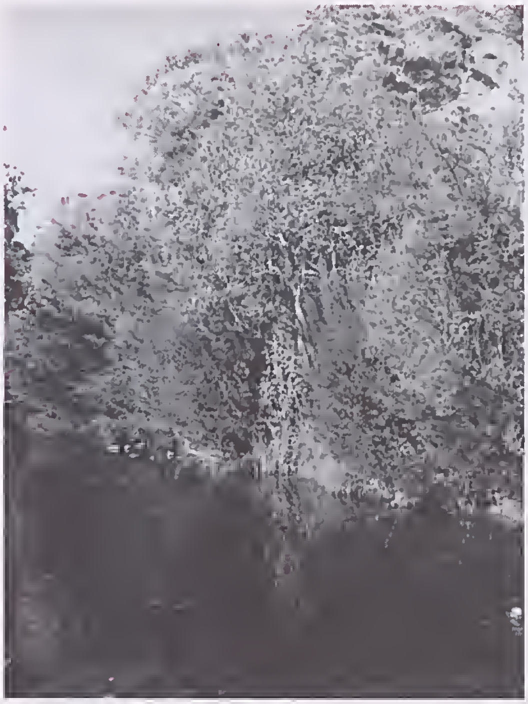


Fig. 2i. Community 9 *Eucalyptus viminalis – E. ovata – E. obliqua – Acacia dealbata – A. melanoxylon* woodland over sedgey–ferny scrub.



Community 9 at Distillery Creek, *Eucalyptus* woodland over sedgey–ferny closed-scrub.

Structural characteristics: The most common structural/dominance types are: *Eucalyptus* woodland or open-forest over heathy, ferny, grassy and/or sedgey closed-scrub; *Eucalyptus* woodland over heathy, ferny, grassy and/or sedgey open-scrub; and *Acacia* open-forest over ferny–sedgey closed-scrub.

Tallest stratum: The most frequently occurring dominant species is *Eucalyptus viminalis* followed by *Eucalyptus obliqua*. *Acacia dealbata* and *Acacia melanoxylon*. Also occurring as infrequent dominants are *Eucalyptus delegatensis*, *Eucalyptus ovata*, *Eucalyptus rodwayi*, *Eucalyptus radiata*, *Eucalyptus regnans*, *Eucalyptus amygdalina*, *Melaleuca ericifolia*, *Leptospermum lanigerum* and *Nothofagus cunninghamii*.

Middle stratum: *Pomaderris apetala* is by far the most common dominant species in the second stratum, followed by *Leptospermum lanigerum*. Also occurring as infrequent dominants are *Acacia melanoxylon*, *Acacia dealbata*, *Acacia mucronata*, *Acacia verniciflua*, *Acacia verticillata*, *Prostanthera lasianthos*, *Melaleuca ericifolia*, *Melaleuca squarrosa*, *Notelaea ligustrina*, *Banksia marginata*, *Coprosma quadrifida*, *Atherosperma moschatum*. *Leptospermum scoparium*, *Pittosporum bicolor*, *Tasmannia lanceolata* and *Dicksonia antarctica*.

Ground stratum: Ferns and sedges are the dominant life-forms in this stratum at most sites. *Blechnum nudum* is the most common fern dominant. *Lepidosperma ensiforme* is the most common sedge dominant. Herbs and grasses do not have extensive cover in this floristic community, often less than 5%. However, at several sites, where grasses are dominant and readily identifiable, *Poa labillardierei* is the dominant species.

Adjacent communities: *Eucalyptus* woodlands and open-forests that have a mixed grassy, heathy, ferny and sedgey understorey.

Closely related riparian floristic community: Community 15.

Affinity with other listed or described community: None

Reservation status: Well-reserved. It is found in the Lost Falls Forest Reserve and the Warrawee Forest Reserve. It is also found in the following insecure reserves: Reedy Marsh Forest Reserve; Jackeys Creek Forest Reserve; Mersey White Water Forest Reserve; Franklin Rivulet Forest Reserve; and Griffin Forest Reserve.

Community 10 at Repulse River, *Eucalyptus* woodland over sedgey–heathy closed-scrub.

Community 10: *Eucalyptus* woodland over *Pomaderris apetala – Pteridium esculentum – Poa labillardierei – Lomandra longifolia – Carex appressa* closed-scrub

Sample sites: 49 Mean no. species: 28 (sd 7.7)

Defining floristic assemblage: *Eucalyptus viminalis, Eucalyptus amygdalina, Pomaderris apetala, Cassinia aculeata, Poa labillardierei, Lomandra longifolia, Carex appressa, Bursaria spinosa, Acacia melanoxylon, Beyeria viscosa, Coprosma quadrifida, Olearia viscosa, Asterotrichion discolor, Lepidosperma laterale, Lepidosperma ensiforme, Polystichum proliferum* and *Leptinella longipes.*

Locations: Mainly in the midlands at altitudes from 20 m to 760 m (Fig. 2j).

Structural characteristics: The most common structural/dominance type is *Eucalyptus* woodland over grassy-sedgey and/or ferny open or closed-scrub. However, *Acacia* woodlands or open-forest over sedgelands or grasslands also characterize this community. *Eucalyptus* species are absent as dominant species in one-quarter of the riparian sites in this community despite nearly all sites being adjacent to dry land vegetation where *Eucalyptus* species dominate in the tallest stratum.

Tallest stratum: The most frequently occurring dominant is *Eucalyptus viminalis* followed by *Eucalyptus amygdalina.* Infrequently occurring dominants are *Eucalyptus pauciflora, Eucalyptus pulchella, Eucalyptus rubida, Eucalyptus delegatensis, Eucalyptus obliqua, Eucalyptus globulus, Eucalyptus ovata, Acacia dealbata, Acacia mucronata* and *Pomaderris apetala.*

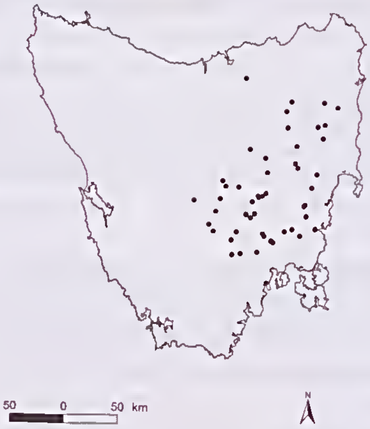


Fig. 2j. Community 10 *Eucalyptus* woodland over *Pomaderris apetala – Pteridium esculentum – Poa labillardierei – Lomandra longifolia – Carex appressa* closed-scrub.

Middle stratum: Shrubs dominate at most sites; *Leptospermum lanigerum* and *Pomaderris apetala* are the most commonly occurring dominants. Also occurring as infrequent dominants are *Cassinia aculeata, Olearia viscosa, Cyathodes juniperina, Asterotrichion discolor, Bursaria spinosa, Banksia marginata, Coprosma quadrifida, Ozothamnus ferrugineus, Ozothamnus thyrsoideus* and *Beyeria viscosa.*

Ground stratum: *Poa labillardierei* and other *Poa* species, *Lomandra longifolia* and *Carex appressa* are the most frequently occurring dominant species. Also occurring as infrequent dominants are *Lepidosperma laterale, Lepidosperma elatius, Lepidosperma ensiforme, Juncus astreptus, Pteridium esculentum, Polystichum proliferum, Leptospermum lanigerum, Cassinia aculeata, Micrantheum hexandrum* and *Acacia mucronata.*

Adjacent communities: All sites adjoin *Eucalyptus* woodland or open-forest that is scrubby, sedgey, grassy or has bracken dominating the understorey.

Closely related riparian floristic community: Community 7.

Affinity with other listed or described community: *Pomaderris apetala – Coprosma quadrifida – Carex appressa – Blechnum nudum* open riparian scrub (51%) (Kirkpatrick et al. 1995).

Reservation status: Unreserved. The community is known from only two reserves, Chauncey Vale Conservation Area and Tooms Lake Forest Reserve, both of which are insecure.

Community 11 at Hydro Creek, *Eucalyptus* woodland over *Leptospermum lanigerum* scrubby heath.

Community 11: *Eucalyptus pauciflora – Eucalyptus viminalis* woodland over *Leptospermum lanigerum* grassy–sedgey closed-scrub.

Sample sites: 16 Mean no. species: 34.1 (sd 8.9)

Defining floristic assemblage: *Eucalyptus coccifera, Eucalyptus delegatensis, Eucalyptus pauciflora, Eucalyptus rodwayi, Eucalyptus rubida, Eucalyptus ovata, Eucalyptus dalrympleana, Pultenaea juniperina, Hakea micracarpa, Notelaea ligustrina, Lomandra longifolia, Banksia marginata, Oxylobium ellipticum, Lomatia tinctoria, Cassinia aculeata, Coprosma hirtella* and *Almaleea subumbellata.*

Locations: Central and eastern Tasmania at altitudes from 220 m to 1020 m (Fig. 2k).

Structural characteristics: There are two main structural/dominance variants in this community: (a) *Eucalyptus* woodland over *Leptospermum lanigerum* sedgey–grassy closed-scrub; and (b) *Eucalyptus* woodland over *Leptospermum lanigerum* scrubby-heath. The ground stratum, dominated by shrubs, grasses and sedges, displays the greatest variation in life-form composition and cover.

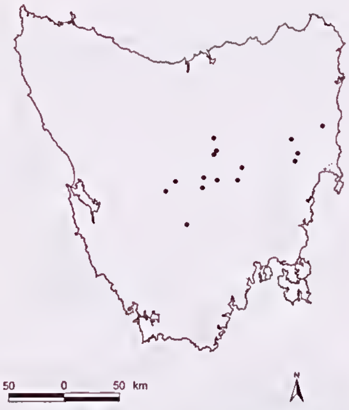


Fig. 2k. Community 11 *Eucalyptus pauciflora – E. viminalis* woodland over *Leptopermum lanigerum* grassy–sedgey closed-scrub.

Tallest stratum: The most common dominant trees are *Eucalyptus pauciflora* and *Eucalyptus viminalis. Eucalyptus delegatensis, Eucalyptus ovata, Eucalyptus amygdalina, Eucalyptus dalrympleana, Eucalyptus rodwayi, Eucalyptus coccifera* and *Eucalyptus rubida* also appear infrequently as dominants.

Middle stratum: *Leptospermum lanigerum* was the dominant shrub in this stratum at most of the sites in this community. *Nothofagus cunninghamii* and *Acacia dealbata* also occurred as infrequent dominants.

Ground stratum: *Leptospermum lanigerum* and *Poa labillardierei* are the most common dominants, where dominant species are evident. Other infrequently occurring dominants are *Cyathodes juniperina, Olearia phlogopappa, Melaleuca gibbosa, Bauera rubioides, Cyathodes parvifolia, Themeda triandra, Lomandra longifolia, Gahnia grandis, Juncus astreptus* and *Carex appressa*.

Adjacent communities: Scrubby *Eucalyptus* woodlands and open-forests, grassy-sedgey Eucalyptus woodlands, and heaths.

Closely related riparian floristic community: Community 10.

Affinity with other listed or described community: None.

Reservation status: Unreserved. The community has not been observed in any secure reserves. It was sampled in three insecure reserves: the Great Western Tiers Conservation Area; Central Plateau Conservation Area (not WHA); and Snowy River Forest Reserve.

Community 12: *Eucalyptus delegatensis* woodland over *Leptospermum lanigerum* grassy–herby–ferny closed-scrub

Sample sites: 8 **Mean no. species:** 37.3 (sd 7.0)

Defining floristic assemblage: *Geranium potentilloides, Hydrocotyle hirta, Blechnum penna-marina, Gonocarpus montanus, Euchiton involucratus, Oxalis perennans, Lagenifera stipitata, Gonocarpus micranthus* and *Carex gaudichaudiana*.

Locations: Central Highlands, Northern Slopes and Ben Lomond bioregions, predominantly in the headwaters and middle order of streams at altitudes from 680 m to 960 m (Fig. 2l).

Structural characteristics: There are two distinctive structural variants in this community: *Eucalyptus* woodland over grassy, sedgey, heathy and/or ferny closed-scrub; and sedgey or herby *Poa labillardierei* grasslands. The ground stratum of this community has the greatest diversity of species and life-forms.

Tallest stratum: The most common dominant species is *Eucalyptus delegatensis. Eucalyptus rodwayi, Eucalyptus amygdalina* and *Eucalyptus pauciflora* also occur as infrequent dominants. *Poa labillardierei* and *Juncus australis* occur as dominants in the treeless sites.

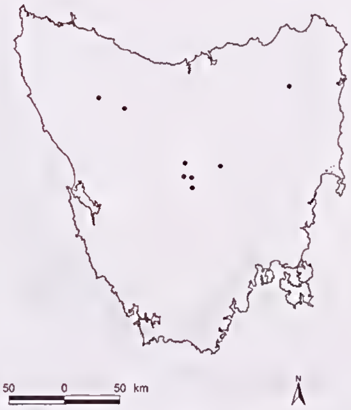


Fig. 2l. Community 12 *Eucalyptus delegatensis* woodland over *Leptospermum lanigerum* grassy–herby–ferny closed-scrub.

Middle stratum: In the variant with trees, *Leptospermum lanigerum* is the most common dominant shrub. *Poa labillardierei, Hydrocotyle* species and *Acaena novae-zelandiae* occur as dominants in the grassland variant.

Ground stratum: Pteridophyta species, mainly *Blechnum penna-marina*, occur as dominants in one-third of the sites. Cyperaceae species, including *Carex gaudichaudiana*, are dominant at three sites. Also occurring as infrequent dominants are *Cyathodes parvifolia* and *Gunnera cordifolia*.

Adjacent communities: Scrubby, shrubby, ferny and heathy woodland and open-forest, and, at one site, *Poa labillardierei* grasslands scattered with *Nothofagus cunninghamii*.

Closely related riparian floristic community: Community 3.

Affinity with other listed or described community: None.

Reservation status: Unreserved.

Community 13 at Wilmot River, *Nothofagus* closed-forest.

Community 13: *Nothofagus cunninghamii – Atherosperma moschatum – Poa labillardierei-Libertia pulchella – Blechnum nudum* closed-forest

Sample sites: 6 Mean no. species: 40.2 (sd 12.2)

Defining floristic assemblage: *Nothofagus cunninghamii, Atherosperma moschatum, Poa labillardierei, Libertia pulchella, Uncinia tenella* and *Aristotelia peduncülata*.

Locations: At altitudes from 40 m to 620 m mainly in northern Tasmania but also along the Franklin River (Fig. 2m).

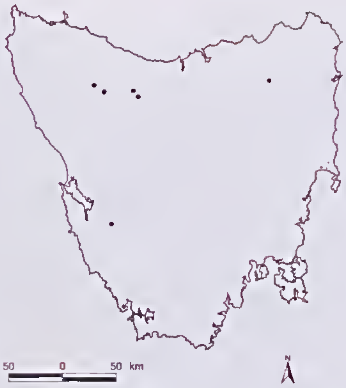


Fig. 2m. Community 13 *Nothofagus cunninghamii – Atherosperma moschatum – Poa labillardierei – Libertia pulchella – Blechnum nudum* closed-forest.

Structural characteristics: There are two equally common structural/dominance variants in this community: (a) *Nothofagus cunninghamii* shrubby, sedgey and/or ferny closed-forest; and (b) *Eucalyptus, Acacia* or *Nothofagus* woodland over *Leptospermum lanigerum* sedgey-ferny closed-scrub. Herbs, grasses and graminoids provide only a sparse covering (<6%).

Tallest stratum: *Nothofagus cunninghamii* is the most common dominant species. *Eucalyptus delegatensis, Acacia dealbata* and *Acacia melanoxylon* also occur as co-dominants.

Middle stratum: *Leptospermum lanigerum* is the most common dominant species. Also occurring as infrequent dominants are *Atherosperma moschatum, Leptospermum riparium, Pomaderris apetala* and *Coprosma quadrifida.*

Ground stratum: Ferns, most frequently *Blechnum nudum* and *Polystichum proliferum*, are the most common dominant species.

Adjacent communities: *Eucalyptus* and *Nothofagus/Acacia* scrubby forest.

Closely related riparian floristic community: Community 19.

Affinity with other listed or described community: None.

Reservation status: Well-reserved. It was sampled in the Franklin-Gordon Wild Rivers National Park and has been observed at several other sites within this secure reserve.

Community 14: *Acacia – Nothofagus – Atherosperma* woodland and forest over *Olearia* shrubland and *Dicksonia antarctica* fernland

Sample sites: 34 Mean no. species: 30.7 (sd 7.6)

Defining floristic assemblage: *Olearia argophylla, Monotoca glauca, Microsorum pustulatum, Rumohra adiantiformis, Juncus pauciflorus, Urtica incisa, Muehlenbeckia gunnii, Grammitis billardierei, Hypolepis rugosula* and *Hymenophyllum flabellatum.*

Locations: At altitudes from 20 m to 900 m mainly in northern Tasmania but also in the upper catchment of the River Derwent (Fig. 2n).

Structural characteristics: There are two distinctive structural/dominance variants: (a) *Nothofagus, Atherosperma* and/or *Acacia* open and closed-forest over *Dicksonia* fernland; and (b) *Nothofagus, Atherosperma* and/or *Acacia* woodland over *Olearia* ferny shrubland. However, there are also structural variants that include *Eucalyptus* species.

Tallest stratum: The most frequently occurring dominant species is *Acacia melanoxylon* followed by *Nothofagus cunninghamii, Acacia dealbata* and *Atherosperma moschatum*. Also occurring as infrequent dominants are *Pomaderris apetala, Eucalyptus obliqua, Eucalyptus regnans, Eucalyptus delegatensis* and *Eucalyptus viminalis.*

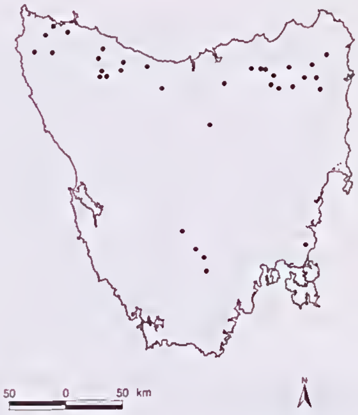


Fig. 2n. Community 14 *Acacia – Nothofagus – Atherosperma* woodland and forest over *Olearia* shrubland and *Dicksonia antarctica* fernland.

Middle stratum: *Pomaderris apetala* is the most frequently occurring dominant species followed by *Dicksonia antarctica.* Also occurring as infrequent dominants are *Leptospermum lanigerum, Nothofagus cunninghamii, Acacia dealbata, Acacia melanoxylon, Olearia lirata, Olearia argophylla, Anodopetalum biglandulosum, Monotoca glauca, Pittosporum bicolor, and Eucryphia lucida.*

Ground stratum: Ferns are the most frequently occurring dominant species in this stratum with *Blechnum nudum, Polystichum proliferum* and *Dicksonia antarctica* the most common. However, *Lepidosperma elatius, Carex appressa, Olearia argophylla, Leptospermum lanigerum* and *Pittosporum bicolor* are also found as infrequent dominants.

Adjacent communities: *Eucalyptus* woodland, open-forest, and closed-forest.

Closely related riparian floristic community: Community 15.

Affinity with other listed or described community: Riparian blackwood/leatherwood forest (51%), *Eucalyptus obliqua – Nothofagus cunninghamii – Polystichum proliferum – Hymenophyllum flabellatum* mixed forest (64%), and *Eucalyptus regnans – Atherosperma moschatum – Acacia dealbata – Olearia argophylla* wet sclerophyll/mixed forest (71%) (Kirkpatrick et al. 1995).

Reservation status: Well-reserved. It was sampled in Roger River State Reserve, Junee Cave State Reserve, Notley Gorge State Reserve, Hellyer Gorge State Reserve, St Columba Falls State Reserve, Mt Barrow State Reserve, and the Sandspit Forest Reserve, and also occurs in several insecure reserves.

Community 15: *Eucalyptus obliqua – Eucalyptus regnans* open-forest over sedgey–ferny *Pomaderris apetala – Olearia lirata* shrubland

Sample sites: 21 Mean no. species: 37.7 (sd 9.6)

Defining floristic assemblage: *Pomaderris apetala, Olearia lirata, Eucalyptus obliqua, Prostanthera lasianthos, Acacia mucronata, Gahnia grandis, Dianella tasmanica, Lepidosperma ensiforme, Pultenaea juniperina, Blechnum minus* and *Sticherus tener.*

Locations: At altitudes from 5 m to 440 m mainly in northern Tasmania but also on the Tasman Peninsula in the southeast (Fig. 2o).

Structural characteristics: The most frequently occurring structural/dominance type in this community is *Eucalyptus/Acacia* woodland or open-forest over ferny closed-scrub. However the structure/dominance types are variable and *Eucalyptus* species are not present in five of the eight infrequently occurring variants of this community.

Tallest stratum: The most frequently occurring dominant species is *Eucalyptus obliqua* followed by *Acacia dealbata* and *Eucalyptus regnans.* Also occurring as infrequent dominants are *Acacia melanoxylon, Acacia verticillata, Nothofagus cunninghamii,*

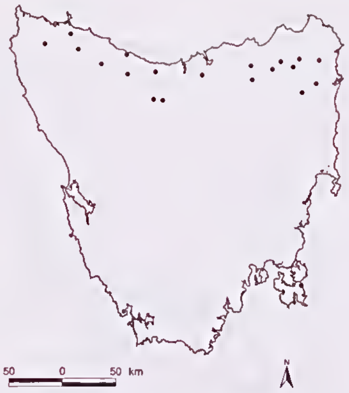


Fig. 2o. Community 15 *Eucalyptus obliqua – E. regnans* open-forest sedgey–ferny *Pomaderris apetala – Olearia lirata* shrubland.

Eucalyptus globulus, Eucalyptus ovata, Eucalyptus viminalis, Leptospermum lanigerum, Pomaderris apetala and *Atherosperma moschatum.*

Middle stratum: The most common dominant species is *Pomaderris apetala*. Also occurring as infrequent dominants are *Leptospermum lanigerum, Acacia melanoxylon, Acacia verticillata, Acacia mearnsii, Acacia mucronata, Nothofagus cunninghamii, Olearia argophylla, Atherosperma moschatum, Coprosma quadrifida, Cassinia trinerva* and *Leptaspermum scoparium.*

Ground stratum: At most sites, ferns and sedges dominate the cover of the ground stratum. *Blechnum nudum* and *Dicksonia antarctica* are the most commonly occurring dominants. *Gleichenia dicarpa* and *Lepidosperma ensiforme* were infrequent dominants.

Adjacent communities: *Eucalyptus obliqua* or *Eucalyptus regnans* ferny, sedgey and/or scrubby woodland or open-forest.

Closely related riparian floristic community: Community 9.

Affinity with other listed or described community: *Eucalyptus obliqua – Nothofagus cunninghamii – Monotaca glauca* mixed forest (57%) and *Eucalyptus regnans – Eucalyptus obliqua – Pomaderris apetala – Olearia lirata* wet sclerophyll forest (58%) (Kirkpatrick et al. 1995).

Reservation status: Well-reserved. It was sampled in the Mathinna Falls Forest Reserve, Holwell Gorge State Reserve and Dip Falls Forest Reserve, and also occurs in several insecure reserves.

Community 16: *Acacia dealbata – Pomaderris apetala – Olearia argophylla – Dicksonia antarctica* ferny–sedgey closed-scrub

Sample sites: 9 **Mean no. species:** 37.3 (sd 6.4)

Defining floristic assemblage: *Dicksonia antarctica, Acacia dealbata, Pomaderris apetala* and *Olearia argophylla* at all sites and the frequent presences of *Eucalyptus regnans, Eucalyptus delegatensis, Tasmannia lanceolata* and *Euchiton collinus.*

Locations: At altitudes between 80 m and 660 m in the central south, and also along the Swan River in the east (Fig. 2p).

Structural characteristics: The community is diverse in structure, with four main variants: (a) *Eucalyptus* or *Nothofagus* woodland over ferny or sedgey closed-scrub; (b) *Acacia* or *Nothofagus* ferny closed-forest; (c) *Acacia* or *Eucalyptus* woodland over ferny open-scrub; and (d) *Atherosperma* woodland over *Dicksonia antarctica* fernland. Ferns are the dominant life-form in the ground stratum.

Tallest stratum: The most commonly occurring dominant species are *Acacia dealbata* and *Nothofagus cunninghamii. Atherosperma moschatum, Eucalyptus delegatensis, Eucalyptus obliqua, Eucalyptus regnans* and *Leptospermum lanigerum* also occur as infrequent dominants.

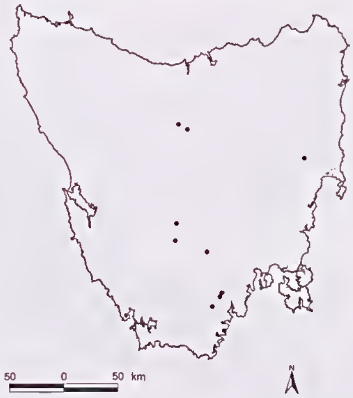


Fig. 2p. Community 16 *Acacia dealbata – Pomaderris apetala – Olearia argophylla – Dicksonia antarctica* ferny–sedgey closed-scrub.

Middle stratum: *Pomaderris apetala* is present at all sites and is the most common dominant species. *Coprosma quadrifida, Nematolepis squamea, Beyeria viscosa, Dicksonia antarctica, Acacia verticillata, Leptospermum lanigerum* and *Nothafagus cunninghamii* also occur as infrequent dominants.

Ground stratum: *Blechnum nudum* and *Blechnum wattsii* are the most commonly occurring dominants.

Adjacent communities: *Eucalyptus regnans* ferny–shrubby open-forest or woodland, and *Eucalyptus delegatensis* woodland over shrubby closed-forest.

Closely related riparian floristic community: Community 15.

Affinity with other listed or described community: *Eucalyptus obliqua – Nothofagus cunninghamii – Monotoca glauca* mixed forest (54%) and *Eucalyptus regnans – Eucalyptus obliqua – Pomaderris apetala – Olearia lirata* wet sclerophyll forest (57%) (Kirkpatrick et al. 1995).

Reservation status: Well-reserved. It was sampled in the secure Meander Forest Reserve and Meetus Falls Forest Reserve.

Community 17 along the King River, *Nothofagus – Acacia* ferny–sedgey–scrubby closed-forest.

Community 17: *Acacia melanoxylon – Nothofagus cunninghamii – Eucryphia lucida – Acacia mucronata* mossy–sedgey–ferny forest and closed-scrub

Sample sites: 49 Mean no. species: 38.7 (sd 9.0)

Defining floristic assemblage: *Nothofagus cunninghamii, Acacia mucronata, Nematolepis squamea, Eucalyptus nitida, Eucalyptus obliqua, Leptospermum riparium, Gleichenia microphylla, Histiopteris incisa* and *Monotaca glauca.*

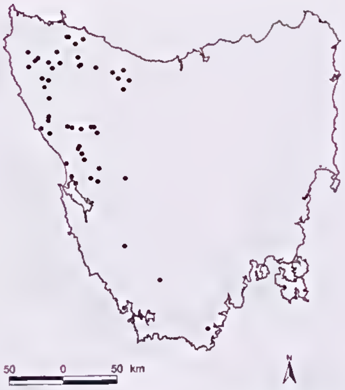


Fig. 2q. Community 17 *Acacia melanoxylon – Nothofagus cunninghamii – Eucryphia lucida – Acacia mucronulata* mossy–sedgey–ferny forest and closed-scrub.

Locations: Widespread in western and northwestern Tasmania at altitudes from 5 m to 420 m (Fig. 2q).

Structural characteristics: The community largely consists of shrubby–ferny open or closed-forests or woodland over ferny–sedgey closed-forest or closed-scrub. The canopy can be dominated by eucalypts or other tree species.

Tallest stratum: The most frequently occurring dominant species is *Acacia melanoxylon*, followed by *Nothofagus cunninghamii*, *Eucalyptus obliqua* and *Eucalyptus nitida*. Also occurring as infrequent dominants are *Acacia dealbata*, *Acacia mucronata*, *Eucryphia lucida*, *Eucalyptus delegatensis*, *Eucalyptus ovata*, *Eucalyptus viminalis*, *Leptospermum lanigerum* and *Leptospermum scoparium*.

Middle stratum: *Leptospermum lanigerum*, followed by *Eucryphia lucida*, *Leptospermum riparium*, *Acacia melanoxylon* and *Acacia mucronata* are the most frequent dominants. Also occurring as infrequent dominants are *Pomaderris apetala*, *Acacia dealbata*, *Nothofagus cunninghamii*, *Anopterus glandulosus*, *Leptospermum scoparium*, *Melaleuca squarrosa*, *Acradenia frankliniae* and *Baloskion tetraphyllum*.

Ground stratum: Shrubs, ferns and graminoids dominate the cover of this stratum. Of the shrubs, *Leptospermum lanigerum* and *Leptospermum riparium* are the most frequently occurring dominants. Of the ferns, *Blechnum nudum* and *Polystichum proliferum* are the most commonly occurring dominants. Of the graminoids, *Baloskion tetraphyllum* is the most frequently occurring dominant.

Adjacent communities: *Eucalyptus* scrubby–ferny open-forests, *Eucalyptus* woodland over closed-scrub, heathy buttongrass plains, and scrubby heath or sedgelands.

Closely related riparian floristic community: Community 19.

Affinity with other listed or described community: Tea-tree mesophytic scrub forest (55%) and *Eucalyptus obliqua – Melaleuca squarrosa – Monotoca glauca* wet sclerophyll forest (51%) (Kirkpatrick et al. 1995).

Reservation status: Well-reserved. It was sampled in the Exit Caves State Reserve, Pieman River State Reserve, Lake Pieman Forest Reserve, the Southwest National Park, and the Franklin-Gordon Wild Rivers National Park.

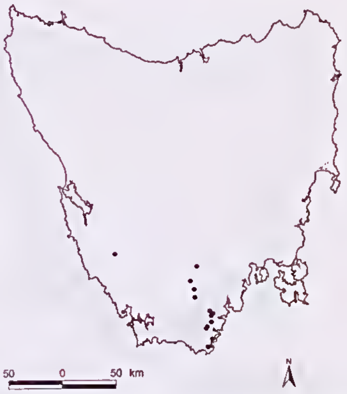


Fig. 2r. Community 18 *Nothofagus cunninghamii – Acacia verticillata – Gahnia grandis* ferny closed-scrub.

Community 18: *Nothofagus cunninghamii – Acacia verticillata – Gahnia grandis* ferny closed-scrub

Sample sites: 13 **Mean no. species:** 40.2 (sd 12.2)

Defining floristic assemblage: There is no species that occurs at every site in this community. However, this community is characterised by the presences of *Acacia verticillata*, *Eucalyptus regnans*, *Acacia riceana*, *Acacia dealbata*, *Olearia stellulata*, *Melaleuca squamea*, *Gleichenia dicarpa*, *Drymophila cyanocarpa*, *Pimelea cinerea* and *Carex fascicularis*.

Locations: Mainly in the far south at altitudes from sea level to 360 m (Fig. 2r).

Structural characteristics: The two most frequently occurring structural/dominance variants in this community are: (a) *Eucalyptus* woodland and open-forest over sedgey–ferny open or closed-scrub; and (b) *Nothofagus* woodland and open-forest over sedgey-ferny closed-scrub.

Tallest stratum: The most frequently occurring dominant species is *Eucalyptus obliqua*, followed by *Nothofagus cunninghamii* and *Eucalyptus regnans*. Also occurring as infrequent dominants are *Eucalyptus globulus*, *Eucalyptus nitida*, *Atherosperma moschatum*, *Acacia verticillata* and *Leptospermum lanigerum*.

Middle stratum: *Leptospermum lanigerum* and *Acacia verticillata* are the most frequently occurring dominants. Also occurring as infrequent dominants are *Anodopetalum biglandulosum*, *Eucryphia lucida*, *Pittosporum bicolor* and *Nothofagus cunninghamii*.

Ground stratum: *Blechnum nudum* is the most commonly occurring dominant and *Gahnia grandis* is co-dominant in half the sites. *Gleichenia dicarpa*, *Gleichenia microphylla* and *Sticherus tener* are also present as infrequent dominants.

Adjacent communities: *Eucalyptus obliqua*, *Eucalyptus regnans* or *Eucalyptus nitida* shrubby or scrubby woodland and open-forest.

Closely related riparian floristic community: Community 17.

Affinity with other listed or described community: None.

Reservation status: Well-reserved. It was sampled in the Franklin-Gordon Wild Rivers National Park, the Southwest National Park, the Hartz Mountains National Park and the Tahune Forest Reserve.

Community 19: *Nothofagus – Eucryphia – Phyllocladus – Trochocarpa – Libertia* shrubby closed-forest

Sample sites: 19 **Mean no. species:** 36.3 (sd 9.5)

Defining floristic assemblage: *Nothofagus cunninghamii*, *Libertia pulchella*, *Anopterus glandulosus*, *Trochocarpa cunninghamii*, *Coprosma nitida*, *Cenarrhenes nitida*, *Trochocarpa gunnii*, *Archeria eriocarpa*, *Oxalis magellanica*, *Hakea lissosperma*, *Richea pandanifolia* and *Blechnum fluviatile*.

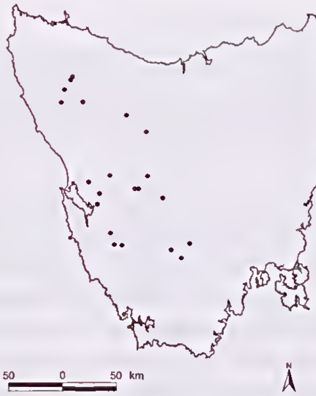


Fig. 2s. Community 19 *Nothofagus – Eucryphia – Phyllocladus – Trochocarpa – Libertia* shrubby closed-forest.

Locations: Western Tasmania at altitudes from 40 m to 940 m (Fig. 2s).

Structural characteristics: The most common structural/dominance type in this community is *Nothofagus/Eucryphia* shrubby closed-forest. The middle stratum has the greatest diversity of species.

Tallest stratum: The most frequently occurring dominant species is *Nothofagus cunninghamii* followed by *Eucryphia lucida* and *Acacia melanoxylon*. Also occurring as infrequent dominants are *Leptospermum lanigerum, Atherosperma moschatum, Eucalyptus nitida, Eucalyptus coccifera* and *Phyllocladus aspleniifolius*.

Middle stratum: The most common dominant species in this stratum is *Eucryphia lucida* followed by *Anopterus glandulosus*. Also occurring as infrequent dominants are *Leptospermum lanigerum, Leptospermum riparium, Atherospermo moschatum, Anodopetalum biglandulosum, Trochocarpa cunninghamii, Cenarrhenes nitida, Pomaderris apetala, Acradenia frankliniae, Dicksonia antarctica, Gaultheria hispida, Hakea lissosperma, Nematolepis squamea*, and *Nothofagus cunninghamii*.

Ground stratum: The most common dominant is *Polystichum proliferum*. Infrequent dominants include *Blechnum wattsii, Blechnum nudum, Dicksonia antarctica, Histiopteris incisa, Sticherus tener, Bauera rubioides, Trochocarpa cunninghamii* and *Libertia pulchella*.

Adjacent communities: Ferny–shrubby closed-forest overtopped by very tall *Eucalyptus* species or *Nothofagus cunninghamii*.

Closely related riparian floristic community: Community 17.

Affinity with other listed or described community: Thamnic leatherwood swamp forest (50%), Thamnic fern swamp forest (53%), Thamnic leatherwood/*Trochocarpa* swamp forest (54%), Thamnic celery top pine swamp forest (54%), Riparian blackwood/leatherwood forest (55%), and *Leptospermum lanigerum – Phyllocladus aspleniifolius – Nothofagus cunninghamii* over *Anopterus glandulosus – Anodopetalum biglandulosum – Telopea truncata* (51%) (Kirkpatrick et al. 1995).

Reservation status: Well-reserved. It was sampled in the Mt Field National Park, the Franklin-Gordon Wild Rivers National Park and the Cradle Mountain-Lake St Clair National Park.

Community 20: *Eucalyptus nitida* woodland over *Leptospermum – Baloskion tetraphyllum – Gymnoschoenus sphaerocephalus* ferny–sedgey closed-scrub

Sample sites: 8 Mean no. species: 34.9 (sd 10.7)

Defining floristic assemblage: *Eucalyptus nitida, Acacia mucronata, Baloskion tetraphyllum, Nothofagus cunninghamii, Gymnoschoenus sphaerocephalus, Diplarrena latifolia, Calorophus elongatus, Gaultheria hispida* and *Lepidosperma filiforme*.

Locations: Mainly in the west in the catchments of the Franklin, Gordon, Henty, Huon, King and Pieman Rivers at altitudes between 160 m and 770 m (Fig. 2t).

Structural characteristics: There are two main structural/dominance variants in this community: (a) *Eucalyptus, Acacia* or *Nothofagus* woodland over sedgey–ferny-heathy closed-scrub; and (b) *Leptospermum* open-scrub over heathy, ferny-grassy buttongrass sedgelands. The ground stratum has the greatest variation in life-forms and species.

Tallest stratum: The most frequently occurring dominant species in the first variant is *Eucalyptus nitida. Acacia mucronata, Acacia melanoxylon and Nothofagus cunninghamii* occur as infrequent dominants. In the second variant, *Leptospermum nitidum, Almaleea subumbellata* and *Melaleuca squamea* occur as dominants.

Middle stratum: *Acacia mucronata* and *Leptospermum scoparium* are the most frequently occurring dominant species. *Leptospermum nitidum, Monotoca glauca, Nematolepis squamea, Melaleuca squarrosa, Bauera rubioides, Gymnoschoenus sphaerocephalus* and *Leptocarpus tenax* occur as infrequent dominants.

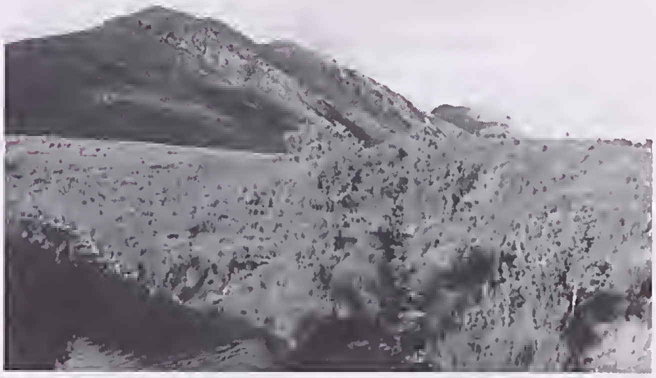
Ground stratum: *Bauera rubioides* is the most frequently occurring dominant shrub. *Gymnoschoenus sphaeracephalus, Lepidosperma laterale* and *Schoenus* species are other frequent dominants.

Adjacent communities: Scrubby, heathy or sedgey buttongrass plains and/or *Eucalyptus nitida* scrubby woodland or open-forest over grassy–sedgey heath.

Closely related riparian floristic community: Community 21.

Affinity with other listed or described community: None.

Reservation status: Well-reserved. It was sampled in the Franklin-Gordon Wild Rivers National Park and the Southwest National Park.



Community 20 at Newton Creek, *Leptospermum* open-scrub over heathy, ferny–grassy buttongrass sedgelands.

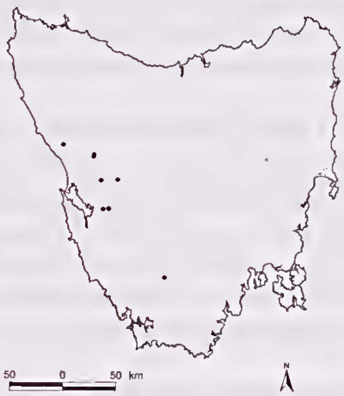
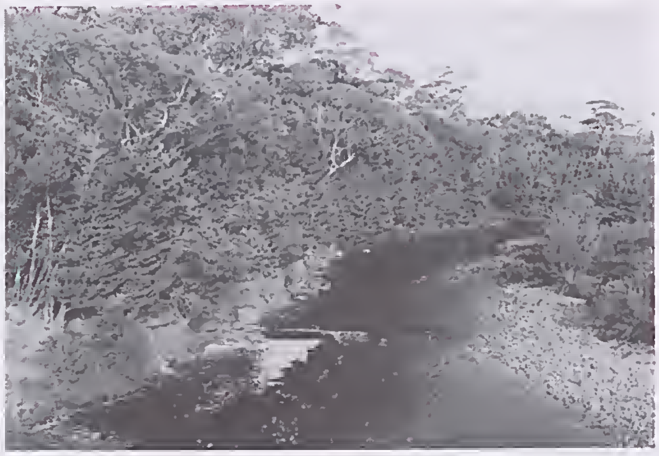


Fig. 2t. Community 20 *Eucalyptus nitida* woodland over *Leptospermum – Baloskion tetraphyllum – Gymnoschoenus sphaerocephalus* ferny–sedgey closed-scrub.



Community 21 at Lindsay River, *Eucalyptus nitida* woodland over *Acacia mucronulata* closed-scrub.

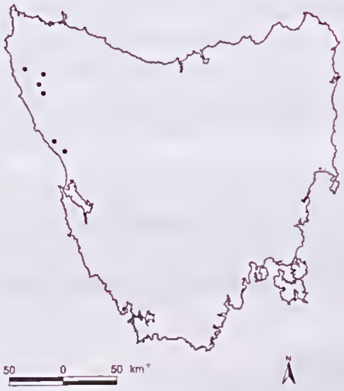


Fig. 2u. Community 21 *Eucalyptus nitida* woodland over *Gleichenia dicarpa – Persoonia juniperina – Philotheca virgata* ferny closed-scrub.

Community 21: *Eucalyptus nitida* woodland over *Gleichenia dicarpa – Persoonia juniperina – Philotheca virgata* ferny closed-scrub

Sample sites: 6 Mean no. species: 34.2 (sd 5.6)

Defining floristic assemblage: *Gleichenia dicarpa* and either *Persoonia juniperina* or *Philotheca virgata*.

Locations: Northwest at altitudes between 160 m and 350 m (Fig. 2u).

Structural characteristics: The community is typically *Eucalyptus nitida* woodland over heathy, sedgey and/or ferny *Melaleuca squarrosa*, *Leptospermum scoparium* or *Acacia mucronata* closed-scrub.

Tallest stratum: The dominant species is almost exclusively *Eucalyptus nitida*.

Middle stratum: *Leptospermum scoparium* and *Melaleuca squarrosa* are present at all sites and are also the most frequently occurring dominant species in this stratum. *Acacia mucronata*, *Leptospermum nitidum* and *Hakea epiglottis* occur as infrequent dominants.

Ground stratum: *Bauera rubioides* is the most frequently occurring dominant shrub. *Gymnoschoenus sphaerocephalus*, *Lepidosperma laterale* and *Schoenus* species are other frequent dominants.

Adjacent communities: *Eucalyptus nitida* scrubby woodland, and sedgey heath.

Closely related riparian floristic community: Community 20.

Affinity with other listed or described community: None.

Reservation status: Unreserved. This community has not been found in any secure reserve. However, it does occur in the insecure Arthur-Pieman Conservation Area.

Discussion

Daley (2003) found that the availability of water through rainfall and hydrological factors significantly influenced the distribution of riparian communities. Rainfall is intrinsically linked with catchment hydrology. The flow regime of a catchment controls the forces governing the appearance and supply of water to riparian areas (Tabacchi et al. 1998). Studies in Oregon, USA (Chapin et al. 2002) and Poland (Wassen et al. 2003) show that: (1) riparian vegetation communities depend strongly on overbank flows; (2) species presence/absence, and the variation in species composition were explained best by flood variables; and (3) river hydrology, together with nutrient release from the soil, were significant for riparian vegetation composition, species richness and productivity.

Tasmanian studies (Hughes 1987, Wintle 2002) show strong relationships between riparian vegetation and hydrological factors. Hughes found that some lateral and cross-section variations in floristic composition away from the river were a response to a flooding gradient, substratum stability and flow frequency. She attributed longitudinal variability in riparian communities to the mobility and dynamic geomorphology of some reaches, as evidenced by erosion and undercutting of banks and riparian vegetation. Wintle found that variation in hydrological regimes explained floristic differences in riparian vegetation communities (Wintle 2002).

That riparian lands provide refuge for native plant species is strongly supported by the present study where nearly half of Tasmania's native plant species, including many threatened species, were detected within the 460 survey sites. While there are only two species in Tasmania that are considered to be obligate riparian species, there are 76 vascular plant species found predominantly in the riparian zone. Nearly 30% of these 'riparian' plants are listed in the Tasmanian *Threatened Species Protection Act 1995*. The majority of riparian plants are shrubs, herbs and sedges. There are only four trees amongst Tasmania's riparian plants, *Eucalyptus ovata* (Black Gum), *Lagarostrobos franklinii* (Huon Pine), *Acradenia frankliniae* (Whitey Wood) and *Callitris oblonga* (South Esk Pine) (Table 3).

Threatened species form a high proportion of the species concentrated in the riparian zone. Some of these species, such as *Callitris oblonga* (Harris & Kirkpatrick 1991), *Acacia axillaris* (Lynch et al. 1999), *Spyridium lawrencei* (Coates et al. 1991) and the *Epacris* species (Keith 2002) may be concentrated in the riparian zone because of the protection that water, rocks and bare ground provide from the ingress of fire. Others, such as *Barbarea australis* (Kirkpatrick & Gilfedder 1998) may be concentrated in the riparian zone because they are susceptible to elimination by stock grazing and require disturbance to provide a suitable seedbed and freedom from competition. As many of the native species found in the riparian zone are herbs and graminoids (Table 1), and these occur in the ground stratum, the major consequences of extensive infestations of shrubby exotic species such as Gorse (*Ulex europaeus*) and Blackberry (*Rubus fruticosus*) are a loss of light required for photosynthesis, a loss of space for growth because of competition, and alterations in nutrient loads and substrate conditions.

Given that disturbance by flood is a normal part of the riparian environment, and that a large variety of possible structural/dominance expressions could occur for any set of species, a floristic classification was used to define riparian communities. Some of the riparian communities are quite distinctive and have very few similarities with other communities (e.g. Communities 1 & 4). However, four of the larger communities have a number of structural and floristic characteristics that are also present in other communities (e.g. see descriptions of Communities 7 & 8, Communities 17 & 18).

Two-thirds of the riparian communities have no close floristic affinity with communities previously described in statewide surveys (Kirkpatrick et al. 1995). In most cases their affinities are with wet eucalypt forest communities, with two being with rainforest communities and one each being with swamp forest and riparian communities. The communities with affinities tend to be largely from high rainfall areas, where the contrast in moisture availability between the riparian zone and adjacent areas is less marked than in the drier parts of the State.

Regional, state and national audits of vegetation rely on the identification of observable and repeatable units (NLWRA 2001), and in most systematic assessments of future conservation areas, units rather than species are stipulated (Pressey & Logan 1998). The 21 riparian floristic communities derived from field surveys and the analysis provide a good platform from which to map riparian communities at the statewide scale, and to make recommendations for conservation. However, the classification of riparian reaches into communities based on floristics creates a degree of difficulty for mapping. While the majority of species that define a riparian floristic community are found in the second or ground strata, it is usually only the tallest stratum that is visible on aerial photographs. The structural diversity of riparian communities is evident from their descriptions. For example, in Community 17 there are several structural manifestations described as open-forest and each of these manifestations would appear different using remote-sensing technology as there are significant visual differences between a *Eucalyptus/Nothofagus* open-forest and *Eucalyptus/Acacia* open-forest. In addition, the structural description, *Eucalyptus/Acacia* open-forest, also exists within Community 14.

Even within a community where there is generic structural classification (e.g. Community 19 closed-forest), the species that dominate the generic structure can be quite varied. This in turn creates difficulties for classifying riparian reaches into communities using only remote-sensing technology.

Two-thirds of the riparian communities are considered well-reserved, using the rather weak criterion of secure reservation in two or more spatially separated situations. Security of riparian vegetation in reserves is likely to depend partly on the degree and nature of up-catchment factors such as alteration to hydrological regimes, spread of exotic species, sedimentation and water quality. With six of the poorly-reserved or unreserved riparian communities, the conversion of one or two insecure reserves to secure reserves would put them in the well-reserved category. Community 12 is not known from any reserve at all, but there is potential for adequate reservation on land owned by the State government.

In the present study sampling was restricted to native riparian vegetation in near natural condition. A significant proportion of Tasmania's remaining native riparian vegetation remains unexplored, undocumented and, in many regions, unreserved and unmanaged. Significant community variation in riparian vegetation in mainland Tasmania has been established. However, there is a need to sample degraded riparian vegetation in gap areas, especially remnants of native riparian vegetation outside existing reserves, with some prioritization of their importance and likely persistence at different levels of management.

With the current move to natural resource management regions within the State and across Australia, it may be timely to re-evaluate the reservation status of floristic communities in general. The current reservation paradigm in Tasmania may provide a high degree of protection for a broad community group but genetic variation within vegetation communities found across several natural resource management regions may be lost. A regional or bioregional conservation paradigm would address this deficiency.

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Appendix: Native vascular species occurring in 30% of the sites in at least one community

(see text for description of communities)

	Communities																				
Taxon	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Number of sites	6	5	11	14	35	9	58	43	33	49	16	8	6	34	21	9	49	13	19	8	6
Lycopodium fastigiatum	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Veronica gracilis	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Viola cunninghamii	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Senecio gunnii	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pratia pedunculata	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Plantago daltonii	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Mimulus repens	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Isotoma fluviatilis	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Hydrocotyle muscosa	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Helichrysum rutidolepis	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Acaena montana	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Taxon	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Number of sites	**6**	**5**	**11**	**14**	**35**	**9**	**58**	**43**	**33**	**49**	**16**	**8**	**6**	**34**	**21**	**9**	**49**	**13**	**19**	**8**	**6**
Geranium sessiliflorum	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Poa costiniana	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Hierochloe redolens	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Juncus sandwithii	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Carex spp.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Richea gunnii	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Orites revoluta	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Leptospermum rupestre	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Bellendena montana	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Myriophyllum spp.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ranunculus spp.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ranunculus triplodontus	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Nymphoides exigua	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Almaleea subumbellata	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Baeckea gunniana	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Gleichenia alpina	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pratia surrepens	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Diplarrena latifolia	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Calorophus elongatus	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lepidosperma filiforme	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Astelia alpina	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+
Austrostipa spp.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Dichelachne spp.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Allocasuarina zephyrea	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lomatia polymorpha	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+
Cotula alpina	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Epilobium billardierianum	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Eucalyptus gunnii	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Leptinella longipes	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Pultenaea daphnoides	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Leucopogon australis	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Acacia sophorae	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Phragmites australis	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Gahnia filum	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Schoenus nitens	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lepidosperma elatius	.	.	.	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Baumea juncea	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Themeda triandra	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lepidosperma inops	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Micrantheum hexandrum	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Hibbertia prostrata	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Hibbertia riparia	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Hibbertia serpyllifolia	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Grevillea australis var. *subulata*	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Grevillea australis var. *tenuifolia*	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Acacia genistifolia	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Callitris oblonga	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Wahlenbergia spp.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Epacris apsleyensis	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Astroloma humifusum	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Allocasuarina littoralis	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ozothamnus ferrugineus	.	.	.	.	.	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.
Eucalyptus globulus	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Taxon	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Number of sites	**6**	**5**	**11**	**14**	**35**	**9**	**58**	**43**	**33**	**49**	**16**	**8**	**6**	**34**	**21**	**9**	**49**	**13**	**19**	**8**	**6**
Senecio linearifolius	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.
Bedfordia salicina	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.
Senecio hispidulus	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.
Gratiola peruviana	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.
Callistemon viridiflorus	.	+	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Baloskion australe	+	+	+	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Empodisma minus	+	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.
Plantago paradoxa	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Austrodanthonia spp.	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ozothamnus hookeri	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Grevillea australis var. *montana*	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Gonocarpus serpyllifolius	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Hypericum japonicum	+	.	+	.	.	+	.	+	.	.	+	+	.	.	.	.	.	.	.	.	.
Epacris gunnii	+	+	+	.	.	.	.	.	.	.	+	+	.	.	.	.	.	.	.	+	.
Carex gaudichaudiana	+	+	+	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Bauera rubioides	+	+	+	.	.	+	.	.	.	.	+	+	.	.	.	.	.	+	.	+	+
Poa spp.	+	+	+	.	.	.	.	.	.	.	+	.	+	.	.	.	.	.	.	.	.
Leptinella reptans	+	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Orites acicularis	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+
Epacris lanuginosa	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+
Melaleuca squamea	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.
Oxylobium ellipticum	.	+	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.
Hakea lissosperma	.	+	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.
Eucalyptus pauciflora	.	+	+	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.
Coprosma nitida	.	+	+	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	+	.	.
Lomatia tinctoria	.	+	.	.	.	.	.	+	+	.	+	.	.	.	.	.	.	.	.	.	.
Hakea microcarpa	.	+	+	.	.	+	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.
Cyathodes parvifolia	.	.	+	.	.	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.
Gonocarpus montanus	.	.	+	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Hydrocotyle sibthorpioides	.	.	+	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Juncus australis	.	.	+	.	.	+	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Blechnum penna-marina	.	.	+	.	.	..	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.
Geranium potentilloides	+	.	+	.	.	.	.	.	+	+	+	+	+	.	.	.	.	.	.	.	.
Poa labillardierei	.	.	+	+	.	+	+	.	+	+	+	+	+	.	.	.	.	.	.	.	.
Oxalis perennans	.	.	+	+	.	+	+	+	+	+	.	+	+	+	.	+	.	.	.	.	.
Lepidosperma ensiforme	.	.	.	+	+	.	+	.	+	.	.	.	.	.	+	.	.	.	.	.	.
Lomandra longifolia	.	.	.	+	+	+	+	.	+	+	+	.	.	.	.	.	.	.	.	.	.
Melaleuca ericifolia	.	.	.	+	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.
Exocarpos cupressiformis	.	.	.	+	.	+	+	.	+	.	.	.	.	.	.	.	.	.	.	.	.
Bursaria spinosa	.	.	.	+	.	+	+	.	+	+	.	.	.	.	.	.	.	.	.	.	.
Acacia verticillata	.	.	.	+	+	+	+	+	+	.	.	.	.	.	.	.	+	+	.	.	.
Leptospermum scoparium	.	.	.	+	+	+	+	.	.	.	.	.	.	.	.	.	+	+	.	+	+
Banksia marginata	.	.	.	+	+	+	+	.	.	.	+	.	.	.	.	.	.	.	.	+	+
Eucalyptus ovata	.	.	.	+	+	+	.	.	+	.	+	.	.	.	.	.	.	.	.	.	.
Eucalyptus amygdalina	.	.	.	+	+	+	+	+	+	+	+	.	.	.	.	.	.	.	.	.	.
Eucalyptus viminalis	.	.	.	+	.	+	+	+	+	+	+	.	.	.	+	.	.	.	.	.	.
Pteridium esculentum	.	.	.	+	+	.	+	.	+	+	.	.	.	.	+	+	+	.	.	.	.
Dianella tasmanica	.	.	.	+	+	.	.	+	+	.	.	.	.	.	+	+	+	.	.	.	.
Eucalyptus obliqua	.	.	.	+	+	.	+	+	+	.	.	.	.	.	+	.	+	.	.	.	.
Lepidosperma laterale	.	.	.	.	.	+	+	.	+	.	.	.	.	.	.	.	.	.	.	.	+
Beyeria viscosa	.	.	.	.	.	.	+	+	+	+	.	.	.	.	.	.	.	.	.	.	.
Acaena novae-zelandiae	+	.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	.	.
Leptospermum lanigerum	+	+	+	.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	.	.

Taxon	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Number of sites	**6**	**5**	**11**	**14**	**35**	**9**	**58**	**43**	**33**	**49**	**16**	**8**	**6**	**34**	**21**	**9**	**49**	**13**	**19**	**8**	**6**
Hydrocotyle hirta	+	.	+	.	+	+	.	+	+	.	+	+	+	+	+	.	+	.	+	.	.
Agrostis spp.	+	.	+	+	+	.	.	+	+	.	.	+	+	.	+	+	.	.	+	.	.
Gahnia grandis	.	+	.	.	+	.	+	+	+	.	+	.	+	.	+	+	+	+	+	+	.
Pultenaea juniperina	.	+	+	.	.	.	.	+	+	.	+	+	+	.	+	+	.	.	.	+	+
Tasmannia lanceolata	.	+	+	.	.	.	.	.	+	.	+	+	+	.	.	+	+	+	+	.	+
Blechnum nudum	.	.	+	.	+	..	.	+	+	.	.	+	+	+	+	+	+	+	+	+	.
Coprosma quadrifida	.	.	.	+	+	.	+	+	+	+	.	.	+	+	+	+	+	+	+	.	.
Acacia dealbata	.	.	.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	.	.
Pomaderris apetala	.	.	.	+	+	+	+	+	+	+	.	.	+	+	+	+	+	+	.	.	+
Gonocarpus teucrioides	.	.	.	+	+	.	.	+	+	.	.	.	.	.	+	.	.	+	.	+	+
Blechnum minus	.	.	.	.	+	.	.	.	+	.	.	.	.	.	+	.	+	.	.	+	.
Acacia melanoxylon	.	.	.	.	+	.	+	+	+	+	.	.	+	+	+	+	+	+	+	.	.
Carex appressa	.	.	.	.	+	+	+	+	+	+	.	+	+	+	+	.	+	.	+	.	.
Pimelea drupacea	.	.	.	.	+	.	.	+	+	.	.	.	+	+	+	+	+	+	+	.	.
Lagenifera stipitata	.	.	.	.	.	+	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.
Juncus spp.	.	.	.	.	.	+	+	+	.	.	.	.	+	.	.	+	.	+	.	.	.
Acacia mucronata	.	.	.	.	.	+	+	.	.	.	.	.	+	.	+	.	+	.	.	+	+
Viola hederacea	.	.	.	.	.	.	+	+	+	.	.	+	+	+	+	+	+	+	+	.	.
Cassinia aculeata	.	.	.	.	.	.	+	+	+	+	+	.	+	+	+	+	.	+	.	.	.
Olearia lirata	.	.	.	.	.	.	.	+	+	.	.	.	.	+	+	.	.	.	.	.	.
Olearia argophylla	.	.	.	.	.	.	.	+	.	.	.	.	.	+	.	+	.	.	.	.	.
Eucalyptus regnans	.	.	.	.	.	.	.	+	.	.	.	.	.	.	+	+	+	.	.	.	.
Polystichum proliferum	.	.	.	.	.	.	.	+	+	+	+	+	+	+	+	+	+	.	+	.	.
Blechnum wattsii	.	.	.	.	.	.	.	+	+	.	.	.	+	+	+	+	+	+	+	.	.
Dicksonia antarctica	.	.	.	.	.	.	.	+	+	.	.	.	+	+	+	+	+	+	+	.	.
Prostanthera lasianthos	.	.	.	.	.	.	.	+	+	.	.	.	+	.	+	.	+	+	+	+	.
Clematis aristata	.	.	.	.	.	.	.	+	+	.	.	.	+	.	+	+	+	.	+	.	.
Juncus pauciflorus	.	.	.	.	.	.	.	.	+	.	.	.	+	+	.	+	.	.	+	.	.
Zieria arborescens	.	.	.	.	.	.	.	.	+	.	.	.	.	.	+	+	.	.	.	.	.
Schoenus spp.	.	.	.	.	.	.	.	.	+	.	+	.	+	.	.	+	.	.	.	.	.
Pittosporum bicolor	.	.	.	.	.	.	.	.	+	.	.	.	+	+	+	.	+	.	.	.	+
Isolepis spp.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	+	.	.	.	+
Notelaea ligustrina	.	.	.	.	.	.	.	.	+	.	+	.	.	.	.	.	.	.	.	.	.
Juncus astreptus	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.
Olearia phlogopappa	.	.	.	.	.	.	.	.	.	.	+	+	+	.	.	.	.	.	.	.	.
Eucalyptus delegatensis	.	.	.	.	.	.	.	.	.	.	+	+	+	.	.	+	.	.	.	.	+
Gonocarpus micranthus	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Euchiton involucratus	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Euchiton spp.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	.	.	.	+
Blechnum fluviatile	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	.
Nematolepis squamea	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	+	+	+	.	+	.
Atherosperma moschatum	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	+	+	.	+	.	.
Nothofagus cunninghamii	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	+	+	+	+	.	.
Anopterus glandulosus	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	+	+	+	.	.
Phyllocladus aspleniifolius	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	+	.	+	.	.
Cyathodes juniperina	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	+	.	+	.	.
Aristotelia peduncnlata	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	+
Oxalis magellanica	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
Pimelea ligustrina	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
Uncinia tenella	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
Ozothamnus thyrsoideus	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.
Drymophila cyanocarpa	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	+	.	.	.
Anodopetalum biglandulosum	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	+	.	.

Taxon	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Number of sites	**6**	**5**	**11**	**14**	**35**	**9**	**58**	**43**	**33**	**49**	**16**	**8**	**6**	**34**	**21**	**9**	**49**	**13**	**19**	**8**	**6**
Libertia pulchella	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	+	.	.
Rumohra adiantiformis	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.
Urtica incisa	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.
Galium australe	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.	.	.	.
Histiopteris incisa	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	.	+	.	+	+	+
Microsorum pustulatum	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	+	.	+	.	.
Hypolepis rugosula	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	+	.	.
Monotoca glauca	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	+	+	.	.	.
Sticherus tener	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	+	+	+	.
Euchiton collinus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Schoenus maschalinus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Billardiera longiflora	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Correa lawrenceana	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Cyathodes glauca	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.
Pimelea cinerea	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.	.	.
Gaultheria hispida	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	.	.
Gleichenia microphylla	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	+	+	+	.	.	.
Leptospermum riparium	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	+
Cenarrhenes nitida	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.	.
Eucryphia lucida	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	.	.
Melaleuca squarrosa	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	+	+	.	+	+
Epacris impressa	.	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	+	+	.	+	+
Eucalyptus nitida	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	+
Acacia riceana	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.
Orites diversifolia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.
Olearia stellulata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	+	.
Grammitis billardierei	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.
Trochocarpa cunninghamii	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.
Pimelea linifolia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.
Philotheca virgata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.
Leptospermum nitidum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.
Eurychorda complanata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.
Ehrharta tasmanica	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.
Gymnoschoenus sphaerocephalus	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+
Sprengelia incarnata	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+
Diplarrena moraea	.	+	.	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+
Leptospermum glaucescens	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+
Hakea epiglottis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+
Telopea truncata	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	+	+
Baloskion tetraphyllum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	+
Leptocarpus tenax	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+
Xyris muelleri	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+
Gleichenia dicarpa	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	+
Rubus gunnianus	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+
Lepidosperma gunnii	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+
Ehrharta spp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+
Spyridium gunnii	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+
Goodia lotifolia	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+
Grevillea australis var. *linearifolia*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+
Mitrasacme pilosa	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+
Myriophyllum pedunculatum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+

Population decline and potential for local extinction in a population of *Pultenaea glabra* (Fabaceae) in Victoria

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Abstract: Pultenaea glabra Benth. is a recently revised taxon which includes disjunct populations in Victoria, NSW, and Queensland. Victorian populations were previously described as *Pultenaea weindorferi* Reader, and listed as rare in Victoria. *Pultenaea glabra* is known from four locations in Victoria; it is locally abundant at the Bunyip and Lerderderg-Wombat localities, is uncommon at Wandin, and is in serious decline at Kinglake. Viable soil-stored seeds were present at all sampled locations, and seed germination was enhanced by heat pre-treatments, though germination of untreated seeds also occurred. Few mature plants remain at Kinglake and the population structure differed markedly from the other sampled populations. It has been suggested that the species requires a specific fire regime for regeneration, but it is likely that the severe decline in the Kinglake population is the result of grazing, rather than an inappropriate fire regime. At this site, germination is occurring but plants have not reached maturity, and the species is represented by only seedlings. Managing the species at Kinglake will require consideration of multiple factors, and reintroducing fire to the site at this stage may jeopardize seedling survival and result in local extinction.

***Cunninghamia* (2004) 8(4): 431–438**

Introduction

For many species, seedling recruitment into fire-prone plant communities relies on seedbank exposure to fire related cues such as heat shock and smoke (Williams et al. 2003). Factors such as seedbank size, seed longevity and depth of seed burial affect germination and recruitment (Tozer 1998, Auld et al. 2000, Brown et al. 2003), and the relative frequency of fire influences the replenishment of seed in the seedbank and population structure (Bradstock et al. 1997). Population structure for individual species is also influenced by the proportion of non-dormant seed in the seedbank (Auld et al. 2000). Obligate seeders are particularly vulnerable to altered fire regimes, and very frequent or very infrequent fires have the potential to contribute to local species extinctions (Bradstock et al. 1998).

Pultenaea glabra Benth. (Fabaceae) is a shrubby obligate seeder and is believed to be dependent on a specific fire regime for regeneration (de Kok & Weston 2002). *Pultenaea glabra* is a slender, erect, usually glabrous shrub growing up to 2 m in height, with yellow flowers in clusters near the ends of branches. It usually occurs as discrete populations within seasonally swampy heath, shrubby woodland and open forest (Reader 1905, Galbraith 1977, Corrick 1980, Woolcock 1989, Walsh & Entwisle 1996, de Kok & Weston 2002). *Pultenaea glabra* includes disjunct populations on the Tablelands and Central Western Slopes of NSW, and Queensland (de Kok & Weston 2002). In Victoria it is known from only four localities: Lerderderg State Park and adjacent Wombat State Forest; Bunyip State Park; Wandin area; and Kinglake National Park (Fig. 1). At Lerderderg and Bunyip the species is locally abundant, and there are many populations with large numbers of individuals present; at Wandin, fewer than 30 plants were located in one population. The population of *Pultenaea glabra* at Kinglake has declined markedly between 1996 and 1999, and now appears to be vulnerable to local extinction. The entire population at Kinglake was burnt in 1962 (McMahon & Stuwe 1982), and some areas were also burnt in 1971 and 1981 (McMahon & Stuwe 1982, Parks Victoria 2001). In 1982, a survey of the 1962-burnt site noted that there were few adult plants, while the areas burnt in 1971 and 1981 had abundant *Pultenaea glabra* plants (McMahon & Stuwe 1982, Woolcock 1989).

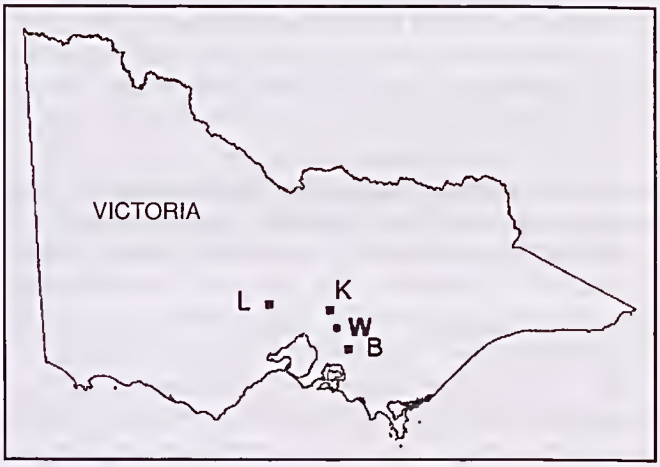


Fig. 1. Locations of *Pultenaea glabra* populations in Victoria. ■ sampled sites L = Lerderderg, K = Kinglake, B = Bunyip; ● not sampled W = Wandin.

In 1996, thousands of mature plants were recorded at Kinglake (N.Walsh, Senior Conservation Botanist, Melbourne Herbarium, Royal Botanic Gardens, pers. comm.) but this population has dramatically declined in numbers, and by 1999 no mature plants could be found (T. Fitzgerald, Ranger, Kinglake National Park, pers. comm.). No mature plants, and remarkably, few dead stems, were located during sampling in 2001 (Fraser 2001). Following natural senescence, at least some dead stems of *Pultenaea glabra* would still be present at the site, which suggests that natural senescence is unlikely to be responsible for the population decline at Kinglake.

Pultenaea glabra is generally believed to be hard-seeded, responding to fire by mass germination, and to display a population structure consistent with discrete recruitment events. Scarlett and Parsons (1993) suggested that low seedling recruitment and the decline in the Kinglake population were caused by changes in fire regime. However, the germination behaviour of NSW populations of *Pultenaea glabra* indicated that they had a large non-dormant seed fraction, and that germination occurred whenever conditions were favourable (Auld 1991, Auld & O'Connell 1991, Morrison et al. 1992). Therefore, if seedlings recruiting in the inter-fire interval fail to reach maturity, the continued conversion of seeds from dormant to a non-dormant state and subsequent germination may severely deplete the seed-bank. The persistence of the Kinglake population is of concern to managers and it has been suggested that reintroducing fire will re-establish this population (T. Fitzgerald, Ranger, Kinglake National Park, pers. comm.). However, simple re-instatement of an ecological process such as fire is unlikely to result in restoration of the population, especially where other components of the ecosystem have been altered (Hobbs & Norton 1996). Exotic herbivores such as deer (Moriarty 2004), goats and rabbits are now part of the Kinglake ecosystem and are known from other studies to affect the success of post-fire vegetation recovery (Cohn & Bradstock 1997). This study aimed to assess the soil-stored seed bank, its germination potential, population structure, site floristics, and soil characteristics of Victorian populations of *Pultenaea glabra*, with a focus on the management implications for the Kinglake population.

Methods

Pultenaea glabra Benth. (Fabaceae) is a recently revised taxon with populations in Victoria, NSW and Queensland (de Kok & Weston 2002). Victorian populations were previously described as *Pultenaea weindorferi* Reader, and this species was listed as rare in Victoria and nationally (Gullan et al. 1990, Briggs & Leigh 1996). The Victorian population at Kinglake displays some taxonomic differences from other populations, having long, soft hairs on the calyx and leaves (Corrick 1980), though it is within the morphological range of *Pultenaea glabra* (Walsh & Entwistle 1996, de Kok &Weston 2002).

Distribution

Collection records from the Melbourne Herbarium, and records and information from other sources (Barry Kemp, ex Department of Conservation Forests and Lands, pers. comm., Stuwe 1980, Kemp 1985) were collated, and all known locations were visited to confirm the presence of *Pultenaea glabra*. Sample sites were selected at representative areas along Buttongrass Track, Bunyip State Park (38º03'S, 145º37'E), O'Brien's Road, Lerderderg State Park (37º29'S, 144º25'E), and from the entire Kinglake National Park site (37º34'S, 145º20'E). The Wandin population was not sampled due to the small number of individuals.

Soil-stored seed

Soil samples were taken to a depth of 5 cm, as most seeds are found within this layer (Hodgkinson et al. 1980, Tozer 1998, Lynch 1999). Twenty-one soil cores were collected at 1 m intervals along two 10 m transects placed perpendicular to each other, and with a mature plant at the intersection of the transects. Each soil core was taken using a 5 cm diameter metal cylinder, and separated into 0–2 cm and 2–5 cm layers. This sampling design was repeated 24 times at Kinglake (504 cores) and six times (126 cores) at Bunyip and Lerderderg. Each soil sample was sieved and examined under a dissecting microscope to recover *Pultenaea glabra* seeds. Seed numbers were recorded separately for the 0–2 cm and 2–5 cm layers, and then bulked for the germination trial. Seed numbers were compared between populations and depths using two-way ANOVA. Data were examined for normality and homogeneity of variances, and the data $\log_{10}$ transformed for analysis. The differences between significant means were examined using Newman-Keuls multiple comparisons test.

Seed bank germination

Seeds from each location were divided into replicates of 20 seeds. Five replicates were heat treated with boiling water for 2 minutes and left to soak for 12 hours, while another 5 replicates (controls) were treated with water at room temperature. Seeds were germinated in a controlled temperature cabinet at 18°C and checked daily for 45 days. After 45 days, ungerminated control seeds were heat treated and left to germinate to establish viability. All germination data were converted to percentages, arcsin transformed, and means compared using one-way ANOVA and a Newman-Keuls multiple comparisons test.

Population structure and characteristics

Population structure was determined by measuring the height and stem diameter of each plant and constructing size-class diagrams. The number of primary branches was counted and used to indicate grazing level (Clunie & Becker 1991). Flowering status, and adult or seedling status (plant <30 cm high) were also assessed. Observations suggested that, while some plants smaller than 30 cm reached maturity and flowered, most flowering plants were greater than 30 cm in height, and a height of 30 cm was arbitrarily chosen for the assignment of individuals into seedling or mature categories. Plant health was estimated on a subjective basis: 'good' = all green foliage and flowering, 'moderate' = some green foliage but remainder of plant is dying, or 'dead' = a stem without any green foliage. At Bunyip and Lerderderg, these variables were measured for all plants in 15 randomly placed 5 × 5 m quadrats, while at Kinglake, the whole site was divided into twelve 50 × 50 m grids and one 5 × 5 m quadrat was sampled randomly within each grid.

Floristics

Vascular plant species were sampled using 3 × 3 m quadrats located within, and adjacent to *Pultenaea glabra* patches, to determine if species composition within populations was floristically distinct. Quadrat size was chosen following construction of species-area curves (Kershaw & Looney 1985). At Bunyip and Lerderderg five quadrats were sampled within, and four quadrats were sampled adjacent to, a *Pultenaea glabra* stand, and at Kinglake, six quadrats were sampled within the stand and eight adjacent to the stand. *Pultenaea glabra* was excluded from the analysis to avoid confounding effects (Coates et al. 1999), and one quadrat at Kinglake was excluded due to having only *Pultenaea glabra* seedlings and no other species present.

Floristic data (based on presence/absence of species) were analysed using the multivariate analysis program PRIMER (Clarke & Gorley 2000), and cluster analysis and non-metric multidimensional scaling was used to elucidate floristic patterns. The Bray-Curtis similarity measure was used to construct the similarity matrix, and clustering used complete linkage.

Soil characteristics

Soil characteristics were examined to establish whether the apparent discreteness of *Pultenaea glabra* populations could be related to soil differences. Within each of the quadrats used for floristics, a random soil core was examined to 50 cm depth. Soil texture, soil pH (CSIRO soil pH test kit) and soil colour (Munsell Soil Color Chart) were assessed in 10 cm depth increments. Resistance to penetration was measured using a Humboldt Pocket Penetrometer, and used as an indirect measurement of topsoil compaction. Three measurements were taken in each floristic quadrat and averaged to produce a representative compaction value for each quadrat. Within stand means and adjacent means were compared using one-way ANOVA and a Newman-Keuls multiple comparisons test.

Results

Soil-stored seed

ANOVA results indicated a significant interaction between populations and soil depth ($F_{2,66}$=8.46, p<0.001) indicating that the variation is population dependent. Newman-Keuls multiple comparisons tests showed that the mean number of seeds at 2–5 cm depth was not significantly different (p<0.05) for the three populations. At Kinglake, the number of soil-stored seeds was not significantly different between the two depths, however Kinglake had significantly fewer seeds at 0–2 cm depth compared with 0–2 cm depth at Lerderderg and Bunyip (Fig. 2). Although the total number of seeds recovered from the three locations was similar, sampling intensity at Kinglake was four times that for Lerderderg or Bunyip and, on a per litre of soil basis, seed density in the 0–2 cm soil layer at Kinglake was very low (Table 1).

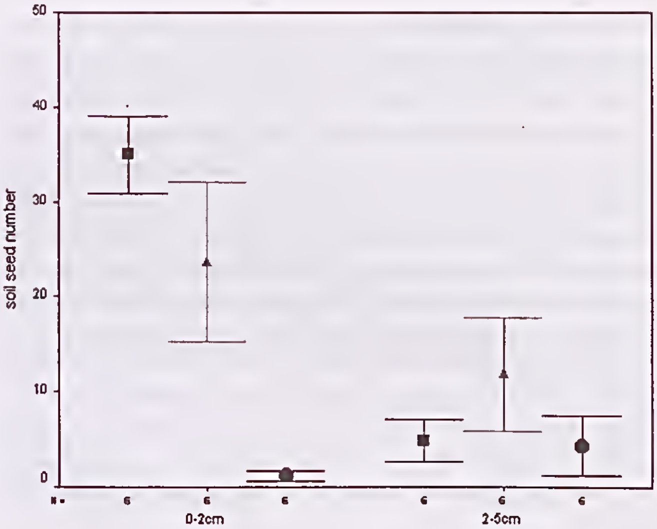


Fig. 2. Seed number (mean ± SE) from two depths for three populations of *Pultenaea glabra*. Lerderderg (■), Bunyip (▲), Kinglake (●).

Table 1. Total soil seed numbers and seed densities (±SE) at two depths for three populations of *Pultenaea glabra*. n = number of samples per population; each sample comprised 21 soil cores.

Location	n	Seed numbers			Seed density (seed/L soil)	
		0–2cm	2–5cm	total	0–2cm	2–5cm
Lerderderg	6	210	29	239	42.7±5.00	3.9±1.77
Bunyip	6	142	69	211	29.0±10.24	13.5±7.48
Kinglake	24	94	186	280	4.8±1.25	6.4±1.68

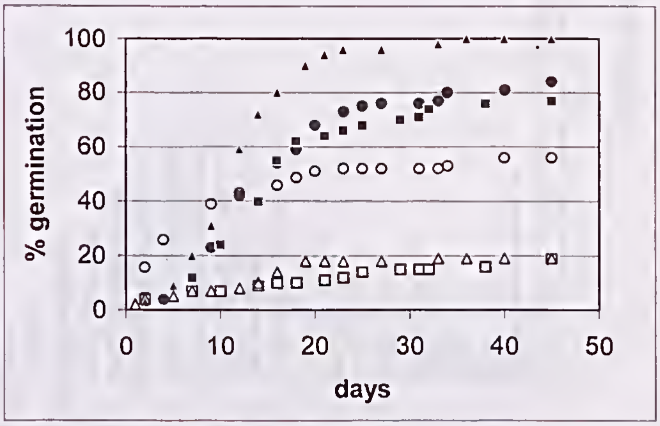


Fig. 3a. Germination (%) of soil-stored seeds of *Pultenaea glabra* at Lerderderg (■), Bunyip (▲), and Kinglake (●); solid symbols = heat treatment, open symbols = controls.

Seed bank germination

Soil stored seed of *Pultenaea glabra* was viable at all three sites. Most seeds had germinated by 25 days and germination reached maximum levels by 40 days (Fig. 3a). Heat treatment of seeds resulted in significantly higher levels of successful germination ($F_{5,24}=24.37$, $p<0.001$) compared with untreated seeds (Fig. 3b). Final germination of seeds from Lerderderg (77%) was not significantly different from Kinglake (84%), but germination of Bunyip seeds (100%) was significantly higher ($p<0.05$, Fig. 3b) than both Lerderderg and Kinglake

A relatively high proportion of untreated (control) seeds germinated. Both Bunyip and Lerderderg had similar untreated germination percentages (20%), while a significantly higher proportion (56%) of untreated seeds from Kinglake germinated ($p<0.05$, Fig. 3b). All ungerminated seeds from the control treatments germinated following heat treatment.

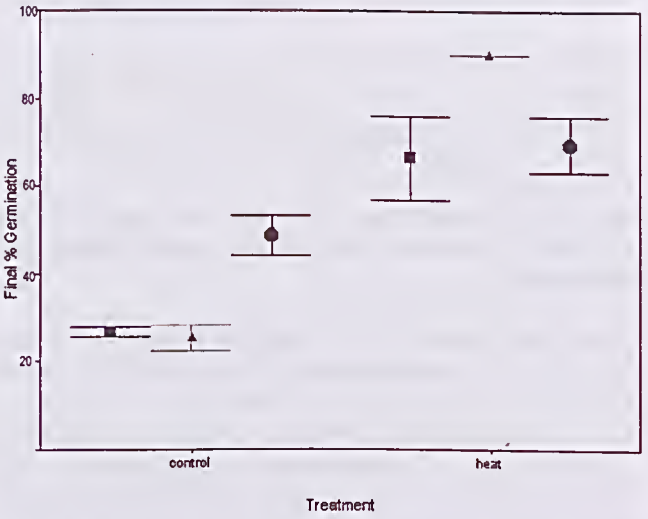


Fig. 3b. Total germination (%) of soil-stored seed (mean ± SE) for three populations of *Pultenaea glabra* at Lerderderg (■), Bunyip (▲), and Kinglake (●).

Population structure and characteristics

Lerderderg and Bunyip populations had similar size distributions, with most plants 1–1.8 m high (Fig. 4). Lerderderg had more slightly larger plants over 150 cm, while Bunyip had slightly more plants less than 150 cm, but the range in heights was very similar. Stem diameters ranged from 0.6–1 cm; only height data are presented. Height was used as a surrogate for plant age. Variations in growth resulting from density effects, and local site conditions would normally result in a range of height and girth size classes for any given age of plants, however sufficiently strong correlations have been found between plant height and plant age for a number of different species (eg. Hazard & Parsons 1977, Stoner 2001) to justify the cautious use of height as an estimate of age. If height data is a good surrogate for age, then the distribution of height classes suggests a steady background level of recruitment of seedlings into these populations (Bowkett & Kirkpatrick 2003), which is consistent with the levels of seed able to germinate without a heat stimulus. The population at Kinglake shows a very different structure, with predominantly

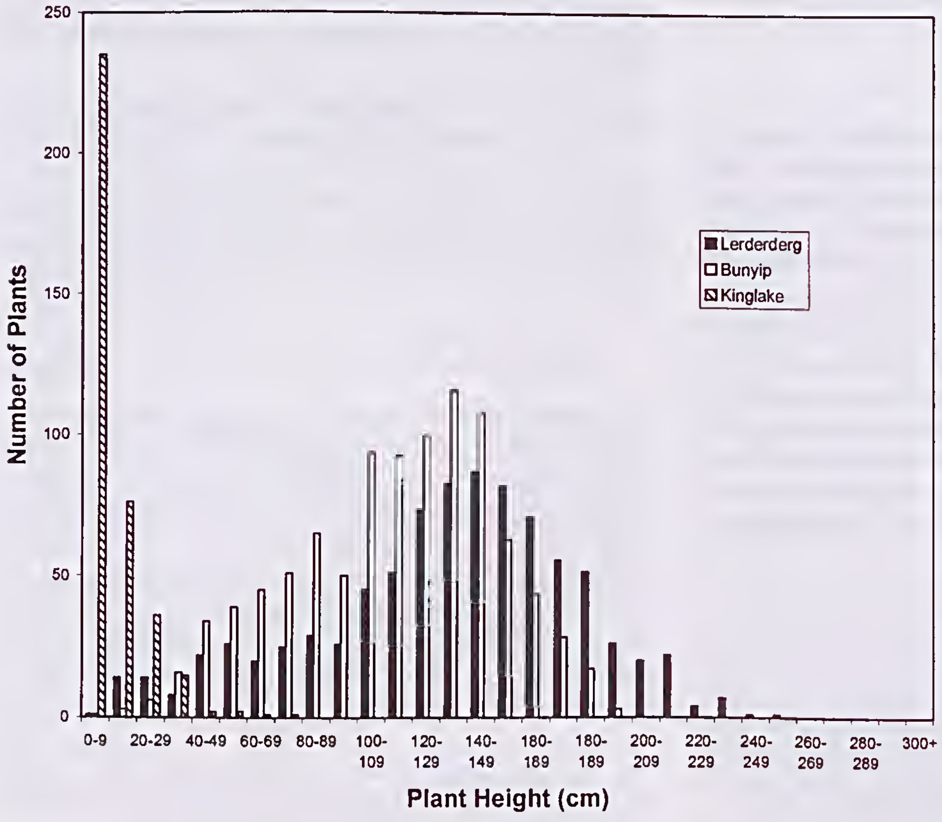
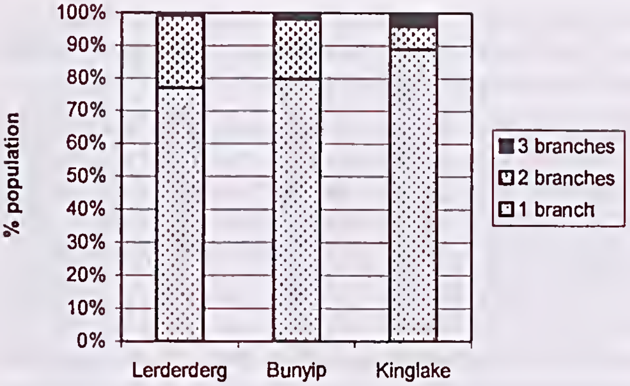
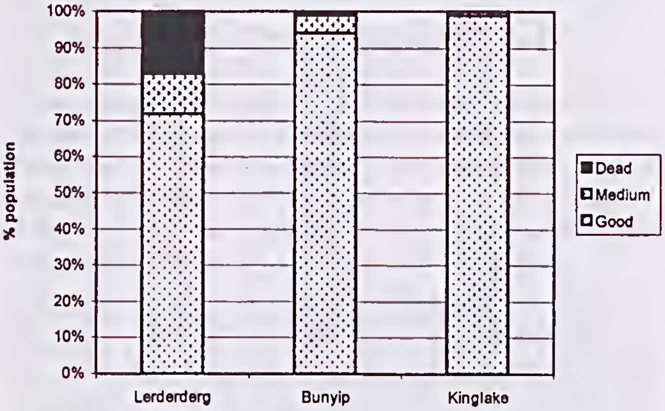


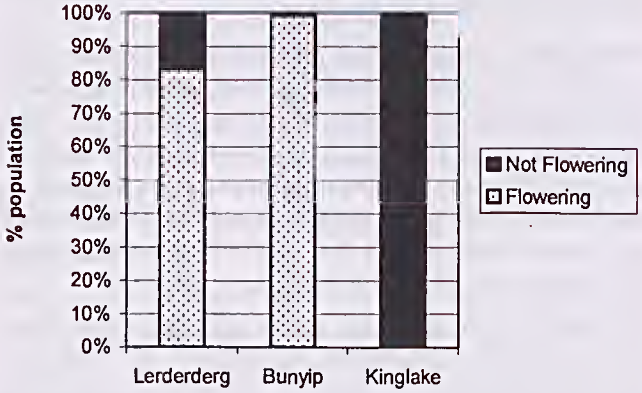
Fig. 4. Plant Height histograms in 10 cm height classes for three populations of *Pultenaea glabra*.



(a) branching



(b) health



(c) flowering

Fig. 5. Branching (a), shrub health (b), and flowering (c) in three populations of *Pultenaea glabra* in Victoria.

immature plants less than 20 cm high, and stem diameters less than 0.5 cm. This suggests a significant difference to the recruitment pattern identified at the other two locations.

Most plants at each of the three locations had one or two primary branches (Fig. 5a), though the Bunyip and Kinglake populations had a small proportion of plants with three primary stems. At Bunyip, this was consistent with the overall larger size of plants, but at Kinglake, where 94% of plants were seedlings, it may indicate more frequent re-shooting following widespread and severe tip pruning by herbivores (Clunie & Becker 1991). Estimates of plant health suggest all three populations are in good condition (Fig. 5b). Most plants sampled at Lerderderg and Bunyip were in flower, while at Kinglake no plants were observed flowering (Fig. 5c), reflecting the immaturity of all plants in that population.

Floristics

Cluster analysis (Fig. 6) and multidimensional scaling (MDS) (Fig. 7) suggest that at Bunyip and Lerderderg, the floristics of the area in which *Pultenaea glabra* grows are subtly different from the adjacent area as there was a general separation between quadrats containing *Pultenaea glabra* and those that did not. At Kinglake the floristic composition within and adjacent to the stand was more homogeneous.

Soil characteristics

Bunyip and Kinglake had loam topsoils over silty loam or clay loam at 50 cm, and Lerderderg had silty clay loam topsoil over light clay at 10 cm and medium clay at 50 cm (Table 2). There were few significant detectable differences in soil characteristics within the *Pultenaea glabra* populations compared to adjacent areas, other than soil penetration resistance ($F_{5,28}=47.73$, $p<0.001$). Bunyip soils showed least resistance, with no differences between areas within and adjacent to *Pultenaea glabra*. Soil resistance in adjacent sites was twice that within *Pultenaea glabra* sites ($p<0.05$) at Lerderderg, while at Kinglake, topsoils were the same throughout, but were nearly five times more compacted than the Bunyip soils ($p<0.05$).

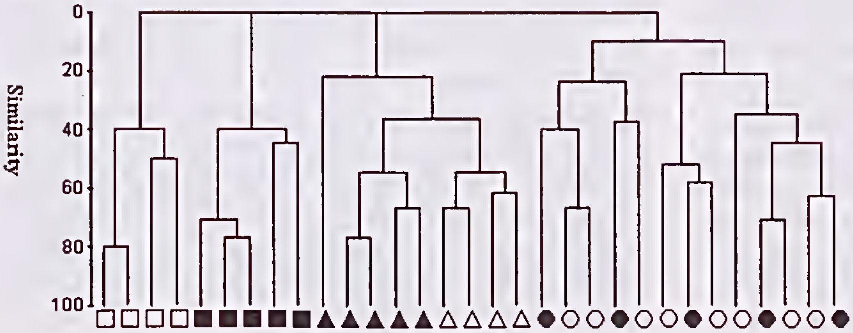


Fig. 6. Cluster ananlysis showing variation in floristics within stands of *Pultenaea glabra* (closed symbols), and adjacent to stands (open symbols) at Lederderg (■), Bunyip (▲), Kinglake (●).

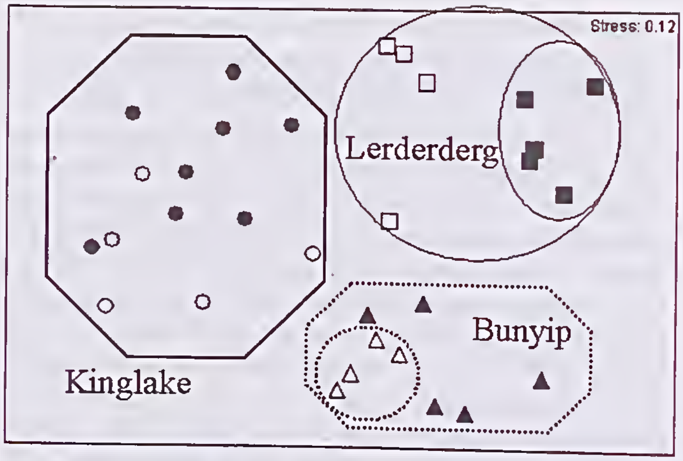


Fig. 7. MDS plot of the floristics within stands of *Pultenaea glabra* (closed symbols), and adjacent to stands (open symbols) at Lerderderg (■), Bunyip (▲), Kinglake (●).

Table 2. Comparison of soil characteristics for three populations of *Pultenaea glabra*. Soil compaction is given within and adjacent to the populations. Compaction means (±S.E.) followed by the same superscript letter are not significantly different at p=0.05.

Variable	Lerderderg	Bunyip	Kinglake
soil texture			
10 cm	silty clay loam	loam	loam
50 cm	medium clay	silty loam	clay loam
pH			
10 cm	4.5	4.7	5
50 cm	6	6	6
colour			
10 cm	2.5Y 6/3	7.5YR 4/1	2.5YR 7/2
50 cm	10YR 5/6	10YR 5/5	10YR 7/6
compaction (kg/cm^2)			
within	0.7±0.1^a	0.5±0^a	2.4±0.2^c
adjacent	1.6±0.2^b	0.5±0^a	2.4±0.2^c

Discussion

Understanding the causes of species persistence at a site, particularly for rare species, is an essential element in their sound ecological management (Keith 2002). Lack of seed, seed size and burial depth, absence of episodic events such as fire which stimulate germination, very specific soil temperatures for germination, physical disturbances, grazing, and limited habitat, have all been proposed as possible contributing factors to natural species rarity (Prober & Austin 1990, Lynch et al. 1999, Lynch 1999, Brown et al. 2003). Lack of specific disturbance, especially lack of fire (Bowkett & Kirkpatrick 2003), may result in local population decline and possibly local extinction.

In Victoria, *Pultenaea glabra* is associated with acidic, seasonally waterlogged soils, swampy areas and drainage lines. This habitat type does not appear to be limited, and like *Pultenaea selaginoides* in Tasmania (Lynch 1999), the restricted distribution of *Pultenaea glabra* in Victoria is unlikely to be due to restricted habitat. Although there was some floristic separation of *Pultenaea glabra* sites from those lacking *Pultenaea glabra*, soil parameters show few differences and did not appear to be associated with the species presence or absence.

The regeneration of many native legume species is promoted by fire (Auld & O'Connell 1991, Williams et al. 2003). Following the mass post-fire regeneration at Lerderderg (Kemp 1985), it was assumed (McMahon & Stuwe 1982, Beardsell n.d, Scarlett & Parsons 1993) that *Pultenaea glabra* was dependent on fire to stimulate germination and the germination response of seeds recovered from the soil seed bank in this investigation is consistent with it being hard-seeded. Heat treatment stimulated rapid onset of germination, and final germination percentages for the three populations (77% to 100%) were consistent with other *Pultenaea* species (Auld & O'Connell 1991, Lynch 1999). The Bunyip and Lerderderg populations had a similar proportion of non-dormant seed (20%) which agrees well with 16.4% reported by Auld & O'Connell (1991). However, the proportion of non-dormant seed was significantly higher (56%) for the Kinglake population. The non-dormant seed fraction reported for other *Pultenaea* species averaged 19.2%, with only one population of one species (*Pultenaea polifolia*) recording 58.9% (Auld & O'Connell 1991, Lynch 1999). Morrison et al. (1992) recorded germination in *Pultenaea glabra* which was not related to fire breaking seed dormancy, but to the high non-dormant proportion of soil-stored seed. They also noted that seed dormancy in *Pultenaea glabra* decreased over time, and suggested that local species persistence depends on the balance between seed loss and successful seedling establishment (Morrison et al. 1992).

The ongoing background germination of the non-dormant seed fraction may explain why the population structures at Bunyip and Lerderderg (Fig. 4) did not conform to that expected of a post-fire obligate seed regenerator. Population structure of species with this regeneration strategy can be expected to show peaks of recruitment coinciding with a regeneration event such as fire, with little recruitment in the inter-fire period (Bowkett & Kirkpatrick 2003).

The Bunyip and Lerderderg populations appear to be multi-aged rather than containing even-aged cohorts related to a dormancy-breaking germination event. Fire may stimulate mass germination and seedling establishment, but the ongoing germination of non-dormant seeds recruits seedlings into the population in the inter-fire interval. This suggests that fire or disturbance is not an obligate requirement for maintaining *Pultenaea glabra* populations. As long as the plants are healthy, flowering, producing seed, and successfully recruiting small numbers of new individuals, the population will persist.

All three populations were last burnt in the early 1980s, and Bunyip and Lerderderg have maintained healthy adult populations over similar time frames without subsequent burning. Since 1981, there has been no fire at Kinglake to stimulate germination, yet large numbers of seedlings <30 cm tall were recorded. This suggests that lack of fire may not be the main cause of the decline in the species at Kinglake.

The seedlings either result from germination of the unusually high proportion of non-dormant seeds, or from patchy mechanical disturbance to the soil which may stimulate germination by abrasion of the seed coat, or both. Mechanical soil disturbance is known to enhance the germination of *Pultenaea selaginoides* in Tasmania (Lynch 1999), and the mosaic of patches approximately 10 m^2 created by the foraging activity of wombats (*Vombatus ursinus*) at Kinglake may contribute to the high numbers of seedlings.

Feral deer numbers increased during the mid-1990s in many areas (including Kinglake), and they can have a significant impact on vegetation structure and floristics (Moriarty et al. 2001, Moriarty 2004). Browsing by feral goats and deer (T. Fitzgerald, Ranger Kinglake National Park, pers. comm.) has been suggested as a possible contributor to the lack of mature plants, and the small increase in secondary and tertiary branch formation at Kinglake also supports the suggestion that seedlings may be browsed by herbivores (Clunie & Becker 1991). Deer are now widespread in Australia (Moriarty 2004) and occur in the Park. Browsing by deer may explain why no dead stems of *Pultenaea glabra* could be found in 2001.

The lack of fire related disturbance since 1981 may also have resulted in floristic changes and increased cover of other plant species. Floristic sampling showed that a thick ground cover of grasses and sedges such as *Gahnia radula* dominates the Kinglake site. Beardsell (n.d.) noted that regeneration of *Pultenaea glabra* amongst the grasses and sedges at Kinglake was very low, and seedlings may not be able to establish in the thick ground layer. Lynch (1999) reported that healthier *Pultenaea selaginoides* populations occurred in more open areas where competition was reduced. Although large numbers of small seedlings were recorded at Kinglake, competition may be a significant factor now preventing the establishment of mature *Pultenaea glabra* at Kinglake National Park.

The future application of fire at Kinglake carries a high ecological risk. Managing *Pultenaea glabra* at Kinglake may require the management of multiple factors, and simply re-introducing fire to the site at this stage may jeopardize survival of existing seedlings and result in local extinction. Burning the site may reduce potential competition from the sedge understorey and stimulate further seed germination, but it will also destroy the large number of seedlings already present. The low soil seed density in the 0–2 cm soil layer at Kinglake compared with the other two populations, may also indicate that many seeds from this soil layer have already germinated and that the seed bank may already be depleted. If the original population decline was influenced by browsing by deer, goats or macropods, and grazing pressures remain high, there is a possibility of local extinction if soil-stored seed is depleted, and establishing seedlings are unable to mature and set seed, to replenish the seed bank. Control of post-fire grazing pressure will need to be a major component of any management option (Meers & Adams 2003), but temporary fencing of the site to allow plants to reach maturity and replenish the seed bank in the absence of fire, may be a less risky option.

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Progress in the recovery of the flora of treeless subalpine vegetation in Kosciuszko National Park after the 2003 fires

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Abstract: The fires of January 2003 burnt much of the treeless high mountain country of Victoria, New South Wales and the Australian Capital Territory, and were the first extensive conflagration of this area since 1939. For this reason there are remarkably few studies of the response of alpine plants and vegetation to fire. A flora survey of treeless subalpine vegetation in the Kosciuszko area in late 2002 sampled 215 sites. Of the 119 sites that were burnt, 60 were relocated and re-sampled in late 2003 to assess the mode and extent of regeneration in a range of treeless plant communities. Twenty-four species (including 3 exotics) were recorded only in the pre-fire sampling. Fifty species (including 18 exotics) were recorded only in the post-fire sampling. One species, *Chenopodium erosum,* had not previously been recorded in Kosciuszko National Park, and is believed to be the first native chenopod recorded in alpine vegetation in Australia. There was no significant difference in mean number of species per quadrat between pre-fire and post-fire quadrats. The average number of weeds per quadrat was, however, significantly greater post-fire. Most of this difference was attributable to the significantly greater number of weeds per quadrat in bog vegetation after the fire. Of the 290 species recorded, 111 species regenerated from seed, 197 species regenerated from resprouting organs (roots, tubers and/or basal stems) and 49 species regenerated from both seed and resprouts. Based on the regeneration observed, most plant communities will return naturally to their pre-fire species composition and cover over a period between a few years and a few decades. Major exceptions will be those communities where the 'keystone' species appear to have been lost at least at a local scale. Principal amongst these are bog communities that incorporated significant biomass of *Sphagnum cristatum* pre-fire, *Podocarpus lawrencei* shrublands and *Celmisia costiniana* closed herbfields. Consideration might be given to augmenting their recovery. It will be important to exclude fire from these communities until their recovery is complete.

***Cunninghamia* (2004) 8(4): 439–452**

Introduction

The fires of January 2003 burnt over 1.4 million ha in north-eastern Victoria, south-eastern New South Wales and the Australian Capital Territory. These fires were started by an intense electrical storm on January 8, igniting many small fires, some of which burnt unchecked before uniting into a massive and destructive fire front. The fires of 1939 are the only recorded fire event comparable in intensity and extent in the Australian Alps.

Few published accounts document the recovery of alpine and subalpine plant communities following fire in Australia (e.g. Kirkpatrick & Dickinson 1984, van Rees & Walsh 1985, Leigh et al. 1987, Lawrence 1999, Wahren & Papst 1999, Wahren & Walsh 2000). Studies that have had the benefit of pre-fire vegetation data are fewer (van Rees & Walsh 1985, Wahren, Papst & Williams 2001, Wahren & Walsh 2000). Other studies investigating response to disturbance in alpine or subalpine areas focus on disturbances that are basically anthropogenic (e.g. skifield or resort development or grazing, Keane et al. 1980, Wahren et al. 1994), these generally being different in nature, extent and response.

This study reports on responses of plants in treeless subalpine plant communities of Kosciuszko National Park (KNP) that were burnt in the January 2003 wildfires. The responses were recorded in quadrats first sampled in November and December 2002, and resampled during the summer of 2003–2004.

Study area

The study area was the treeless subalpine plains of KNP (Fig. 1). Treeless plains occupy valley bottoms from the lowest parts of KNP (c. 1100 m) to near the limit of tree growth (c. 1900 m). The absence of trees is attributed to the low temperatures and frost associated with cold air drainage and pooling, which limit tree establishment and survival (Harwood 1980). All of the sampled sites receive regular winter snowfalls but snow persists for long periods only on the higher sites, generally over 1400 m. The annual rainfall ranges from 1680 mm in the western part of the study area at Cabramurra to 1835 mm at Thredbo in the east. Soils range from alpine humus to peat and tend to be highly acidic. They overlay parent material of a range of types including granite, basalt, limestone and shale. The vegetation is largely grass-dominated, although some of the rocky rises within plains are shrubby. *Eucalyptus lacrimans* is an occasional dominant of ridges and hilltops in the Kiandra area. *Sphagnum*-dominated bogs are occasional in drainage lines. Subalpine treeless plains in KNP may be floristically highly diverse (McDougall & Walsh 2002).

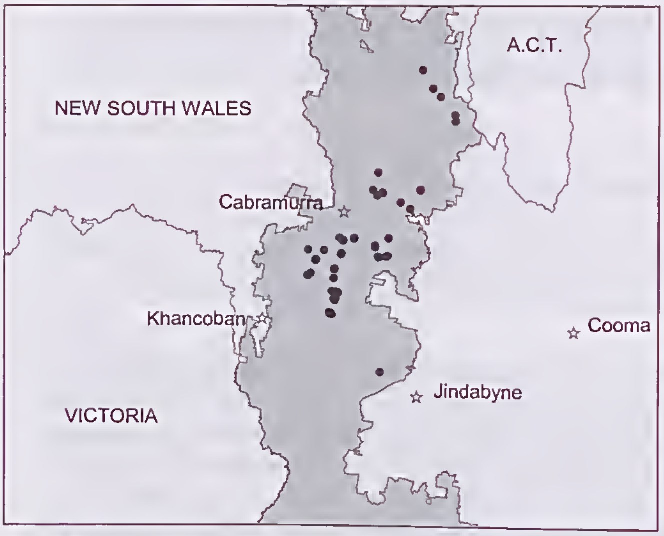

Fig. 1. Location of quadrats (circles) in Kosciuszko National Park (shaded).

Methods

In November and December 2002 we sampled areas of treeless subalpine vegetation in the Kosciuszko area with a view to constructing a community classification of these vegetation types throughout the south-eastern Australia mainland. This work would add to studies previously published for similar vegetation in Victoria (McDougall 1982, Walsh et al. 1984). Sites investigated during this study were based on 5 × 5 m quadrats, located using GPS coordinates (accurate to c. 3 m), and described using site attributes (such as slope, aspect and vegetation structure) and all vascular plant species recorded using the Braun-Blanquet cover/abundance index.

Of 215 sites sampled during the 2001–2003 period, 119 were burnt to some extent in January 2003. An attempt was made to accurately relocate as many of the burnt sites as possible by using GPS locations, field notes, memory, and the species lists previously compiled. Quadrats were only re-sampled if they could be confidently relocated and more than about 75% of the quadrat was burnt. Species that were present in quadrats only as 'fire-escapers' in partly burnt quadrats were noted but not included in data analyses. Sixty quadrats were re-sampled. Although it is possible that the re-sampled 5 × 5 m quadrats may not have precisely overlain the quadrats sampled in 2002, quadrats were initially carefully chosen to lie in uniform vegetation so the variance between the two sampling periods due to spatial incongruence alone should have been minimal. Species not recorded in the post-fire sampling may have been overlooked due to the diminutive or cryptic nature of seedlings, but we believe oversights of this nature are probably relatively insignificant in the overall analysis. Groups most likely to have been misidentified or overlooked were seedling grasses and sedges, different species of which are very similar at the young seedling phase. Juvenile forbs that were unable to be identified in the field were collected from outside quadrats and grown on to maturity under nursery conditions for subsequent identification.

The selected quadrats were pegged with a stainless steel marking pin for future reference and pairs of digital photographs, centred on each site, were taken from opposite directions. Within each quadrat, all species were recorded with an estimate of cover based on the Braun-Blanquet cover scale (Braun-Blanquet 1932). An estimate was also made of total percentage vegetative cover. The method of regeneration was recorded for each species (where possible) as was the phenological (flowering/vegetative) state. Opportunistic observations of species regeneration were made in similar vegetation in other parts of the Australian Alps during the summer of 2003/04.

Data analysis

The significance of differences in the numbers of species per quadrat and numbers of weeds per quadrat between the pre-fire and post-fire samples was determined using *t*-tests for paired samples for each broad vegetation group. The significance of differences in total % vegetative cover between broad vegetation groups post-fire was determined using a *t*-test. Although total % vegetative cover was not measured before the fire, all quadrats used in the analysis had close to complete cover at that time as is typical for similar undisturbed alpine and subalpine communities (Carr 1977, Williams & Ashton 1987a). Quadrats containing a large proportion of rock were excluded from the analysis.

Results and discussion

In broad categories, the 60 quadrats sampled comprised 13 bog/wet heath, 9 fen/wet grassland, 8 dry grassland, 16 open heath, and 14 closed heath vegetation examples. A total of 290 vascular plant species (including 27 exotics) were recorded (Appendix). Twenty-four species (including 3 exotics) were recorded only in the pre-fire sampling — five of these had been recorded in more than two pre-fire quadrats: *Cotula alpina* (3 quadrats), *Epacris celata* (3), *Epacris petrophila* (7), *Olearia algida* (6), *Richea continentis* (6). Fifty species (including 18 exotics) were recorded only during the post-fire sampling — six (including three exotics) of these were recorded in more than two post-fire quadrats: **Cerastium glomeratum* (5 quadrats), **Cirsium vulgare* (12), *Dichelachne crinita* (4), *Picris angustifolia* subsp. *merxmuelleri* (3), **Trifolium campestre* (3), *Veronica gracilis* (5). Although many of the new species found in quadrats were seen only occasionally, the grass *Dichelachne crinita* was abundant and obvious in the Broadway Plain area south of Tooma Dam. It was not observed at all there in the previous summer. Within the first year after burning, 39% of native species were observed to flower.

There was no significant difference in mean number of species per quadrat between pre-fire and post fire quadrats, although there were significantly more species per quadrat in open heathland quadrats before the fire than after (Table 1). The average number of weeds per quadrat was significantly greater post-fire. Most of this difference was attributable to the significantly greater number of weeds per quadrat in bog

Table 1. The number of species / quadrats and weeds / quadrat (± SE) in each broad vegetation grouping, pre- and post-fire. The significance of differences between means for each vegetation grouping and the total quadrats was determined by *t*-tests for paired samples; * *P* < 0.05; ** *P* < 0.01

	Species / quadrat		Weeds / quadrat	
Vegetation Grouping (n)	**Pre-fire**	**Post-fire**	**Pre-fire**	**Post-fire**
Bog / wet heath (13)	20.5 ± 0.7	22.6 ± 0.8	0.5 ± 0.2	2.3 ± 0.4**
Fen / wet grassland (9)	21.8 ± 0.8	19.7 ± 0.8	2.3 ± 0.5	3.0 ± 0.7
Dry grassland (8)	23.7 ± 0.9	26.6 ± 0.8	3.0 ± 0.6	3.6 ± 0.7
Open heathland (16)	30.6 ± 0.6	26.2 ± 0.7*	2.1 ± 0.3	2.6 ± 0.4
Closed heathland (14)	22.0 ± 0.6	22.8 ± 0.7	1.2 ± 0.3	1.6 ± 0.3
All quadrats (60)	24.3 ± 0.3	23.7 ± 0.4	1.7 ± 0.2	2.5 ± 0.2**

vegetation after the fire. Almost half of the exotic species newly recorded in quadrats after the fire were found in bog quadrats: *Acetosella vulgaris* (3 quadrats), *Agrostis capillaris* (1), *Bromus hordeaceus* (1), *Cerastium vulgare* (1), *Cirsium vulgare* (5), *Conyza bonariensis* (1), *Hypochaeris radicata* (3), *Salix cinerea* (1), *Taraxacum officinale* (1), *Trifolium arvense* (1), *Trifolium campestre* (2), *Trifolium repens* (3), *Vulpia bromoides* (1).

Fire behaviour

The fire burnt in all of the broad vegetation groups sampled. Its intensity and extent were variable, even at a very small scale, with small patches of vegetation escaping the fire within an otherwise charred landscape. Although the fire burnt much of the woody vegetation, there were some shrubs and trees that commonly escaped: patches of unburnt *Leptospermum grandifolium* were often observed in gullies in subalpine forest; the fire, although intense in the Happy Jacks Plain area, only partly burnt a large *Podocarpus lawrencei* shrubland bordering a block stream; small patches of snow gum (*Eucalyptus pauciflora* and *E. niphophila*) were apparently untouched next to patches that had had their crowns burnt.

The severity of the fire was not always obviously correlated with the amount of fuel present. Two sparsely vegetated rocky outcrops near Happy Jacks Plain were burnt so severely that even many resprouting species could not be located after the fire, and of the 76 species recorded in two quadrats before the fire, only 40% were relocated. A wet area adjoining one of the outcrops, where a quadrat had been sampled before the fire, was completely devoid of vegetation and had eroded to a depth of about 3 cm below the original soil surface (Fig. 2). The quadrat could not be accurately relocated as there were no hints of its original position.

In some grasslands where the fire had been less severe, burning had apparently only occurred where shrubs had grown and in their immediate vicinity. Many such grasslands were otherwise untouched by the fire. The severity of the fire in grasslands appeared, in places, to be related to the density of the dominant *Poa* species — some dense *P. costiniana* grasslands being lightly singed whilst more open *P. hookeri* and *P. clivicola* grasslands being more comprehensively consumed. Bog vegetation, when burnt at all, was commonly burnt severely, even when the adjoining grassland communities were unburnt or barely singed. A very light fire in bog vegetation was often enough though to kill plants such as *Richea continentis*, which were sometimes found dead with their leaves intact and no indication of burning.

The patchiness of the fire has important implications for the way its impact is evaluated now and in the future. Spatial studies of fire impact (where the vegetation on opposite sides of a fire boundary are compared) must assume that the burnt and unburnt vegetation were of equal fire risk and that both sides of the boundary were floristically similar before the fire. From our observations many fire boundaries would not make for reliable comparisons of burnt and unburnt vegetation. As recovery occurs and the signs of the fire disappear, patches of fire-escaped vegetation will blend into the overall burnt landscape. Maps of fire extent will probably not be at sufficient resolution to allow detection of fire-escaped patches so there is a danger that future assessments of fire recovery will assess both burnt and unburnt vegetation. Aerial photography might be used as a future check on fire status.

Regeneration strategies

Of the 290 species recorded, 111 species regenerated from seed, 197 species regenerated from resprouting organs (roots, tubers and/or basal stems) and 49 species regenerated from both seed and resprouts (Appendix).

In general, grassland species (e.g. *Poa* spp., *Austrodanthonia* spp.), sedges (*Carex breviculmis, C. hebes*), daisies (e.g. *Brachyscome* spp., *Craspedia* spp., *Leptorhynchos squamatus*, *Senecio* spp.) and other forbs (e.g. *Plantago euryphylla*, *Ranunculus graniticola*) were largely or entirely resprouters. The vegetative cover in wet and dry grasslands was significantly higher 10 months after the fire than in the other broad vegetation types assessed (Table 2). By that time, short grasslands dominated by *Poa hookeri* had apparently more or less returned to their pre-fire vegetative cover and species composition.

Shrublands were dominated by a relatively high proportion of species that were dependent on seedling recruitment (e.g. *Phebalium squamulosum, Grevillea australis, Asterolasia trymalioides, Westringia lucida*), although some shrubs were noted only as resprouters (e.g. *Hakea microcarpa, Orites* *lancifolia*, *Tasmannia xerophylla*, *Olearia* spp.), and some exhibited both strategies (e.g. *Bossiaea foliosa*, *Hovea montana*, *Oxylobium ellipticum*, *Podolobium alpestre*). Shrublands appeared to have burnt at very high temperatures, presumably due to their architecture and the inherent flammability of the plants themselves. Much of the woody material and usually all leaf litter was burnt (in contrast to most other broad vegetation types), resulting in the lowest cover of vegetation following fires (Fig. 3, Table 2). This group of communities is probably most prone to soil loss in the immediate (up to c. 2 years) post-fire period.

Table 2. Mean and range of total % plant cover (± SE) in each broad vegetation grouping post-fire. The significance of differences in means between vegetation groupings was determined by multiple *t*-tests. Means with the same superscript letter are not significantly different, $P > 0.05$.

	Total plant cover (%)	
Vegetation Grouping (n)	**Mean (± SE)**	**Range**
Bog / wet heath (13)	31 ± 6^{ac}	5–75
Fen / wet grassland (9)	56 ± 10^{b}	10–95
Dry grassland (8)	58 ± 8^{b}	25–90
Open heathland (11)	38 ± 8^{a}	2–70
Closed heathland (13)	16 ± 4^{c}	1–40

Open heathlands showed a regenerative response somewhere in between those of the grasslands and shrublands, sharing many of the species of those structural types, but generally, extreme soil exposure was limited to those areas underlying non-resprouting shrubs (chiefly *Grevillea australis* and *Asterolasia trymalioides*).

Bog vegetation, dominated by *Sphagnum cristatum*, showed perhaps the greatest loss of important structural species following fire. Apart from *Sphagnum* itself, which is generally dependent on remnant unburnt fragments for regeneration (fertile plants having been very rarely reported in the Australian high country), the woody epacrids (*Epacris celata*, *E. gunnii*, *E. petrophila*, *Richea continentis*) are almost entirely dependent on seedling recruitment for re-establishment following fire. Studies of burnt bog vegetation in Victoria (NGW pers. obs.) have shown the time for germination in these species may be as much as 18 months. These data are consistent with the responses of this group of plants in KNP. Conversely, other shrubs in bogs such as *Baeckea gunniana* and *Callistemon pityoides* are strong resprouters. The peats underlying the bogs and wetter patches of *Sphagnum* generally retained some moisture and, in most cases, resisted complete combustion, but in the most severely burnt examples, the peats burnt down to mineral soils (Fig. 4).

Overall, there were very few species that were found much less frequently in post-fire quadrats than in pre-fire quadrats (Table 3). Several of these were the obligate seeding shrubs mentioned above. The species found less frequently in post-fire quadrats may simply be the slowest to regenerate. *Kunzea muelleri*, for instance, which forms large, layering mats had only begun to resprout in occasional patches at the time of

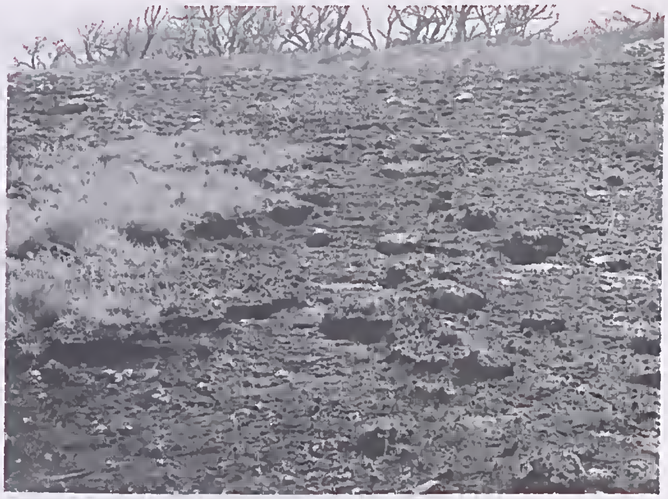

Fig. 2. Erosion in a damp area near Happy Jacks Plain following the fire. The quadrat at this site could not be relocated as all plant material had disappeared.

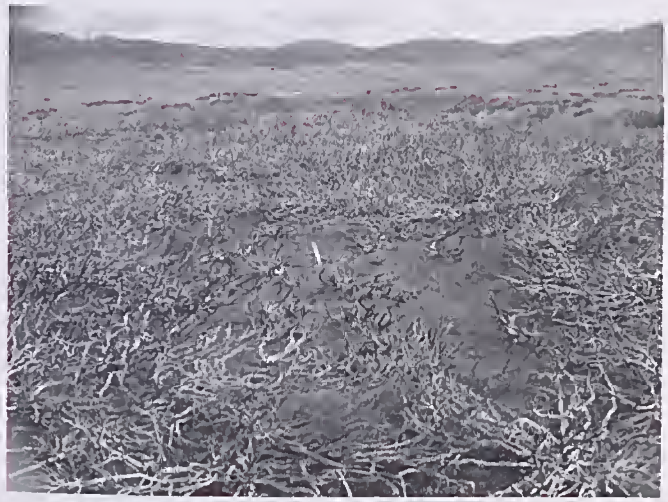

Fig. 3. There was often almost no plant cover in shrub dominated communities one year after the fire. Sites such as this will be vulnerable to soil loss for much longer than surrounding grasslands.

Table 3. Species apparently disadvantaged by fire in the year after the fire (pre-fire frequency more than twice the pre-fire frequency and occurring in at least 4 quadrats pre-fire). Species records for escapes from the fire are not included in the post-fire frequency.

Species	f pre-fire	f post-fire
Epacris gunnii	19	2
Epacris petrophila	7	1
Euphrasia collina subsp. *paludosa*	12	3
Grevillea australis	21	6
Hypericum japonicum	8	2
Kunzea muelleri	14	4
Luzula flaccida	13	6
Melicytus dentatus	8	3
Olearia algida	7	1
Oreomyrrhis ciliata	13	3
Pimelea biflora	7	1
Prasophyllum sphacelatum	5	2
Ranunculus millanii	6	2
Richea continentis	6	0
Scleranthus biflorus	25	4

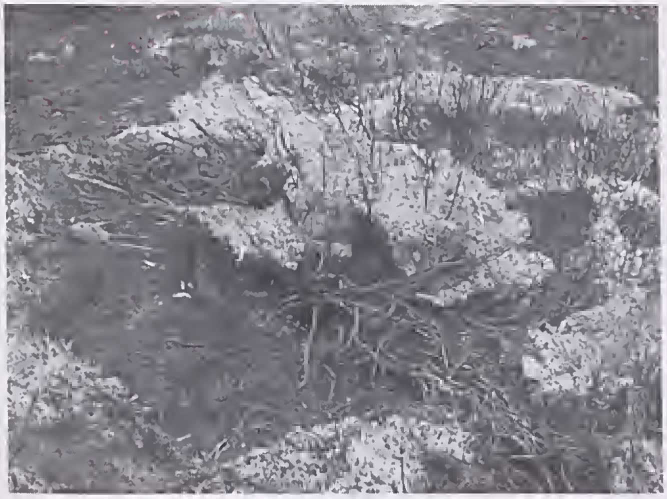

Fig. 4. The complete cover of *Sphagnum cristatum* at this bog on Rennix Plain was severely disprupted by the fire and some hummocks have been left isolated from their water supply. The fire commonly burnt along the stems of epacrids through the *Sphagnum* layer and deeply into the peat below. Photo: Colin Totterell.

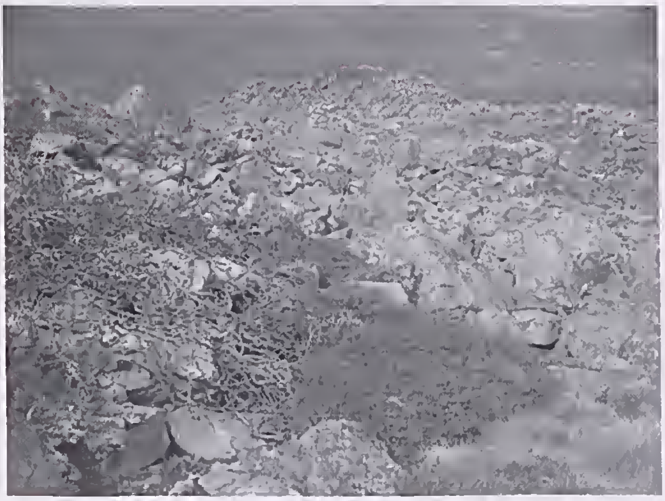

Fig. 5. Although the majority of stems of *Podocarpus lawrencei* plants were killed in this population, some branch tips survived. These may allow the rapid regeneration of this species in such sites. The tussocks adjoining the shrubland were untouched by the fire.

the post-fire survey. More extensive regeneration was observed later in the summer of 2003–2004 (c. 15 months after the plants were burnt).

Although there is no reason to expect that regeneration will not ultimately be seen in all of the species disadvantaged in the short-term – there have been other fires in the high mountain areas even in the 20th Century — some long-lasting effects are likely. Resprouting of completely burnt *Podocarpus lawrencei* shrubs, some subsequently found to be more than 200 years old (A. Schatunowski, Australian National University pers. comm.), has not yet been observed. The large stems of burnt veterans of this species appear to be dead. Short leafy branchlets resprouted along lightly burnt *Podocarpus* stems in the Perisher Ski Resort in KNP but most of these had died by March 2004 (KLM pers. obs.). Abundant *Podocarpus* seedlings were observed at Perisher at that time and these were also observed in areas burnt by the 2003 fires on the Cobberas Mountains, Victoria (F. Coates pers. comm.). Significant recovery of many of the *Podocarpus* shrub communities on block streams, the primary habitat for the Mountain Pygmy Possum, may only be seen by the next generation of plant ecologists. Another fire before the current cohort of *Podocarpus* seedlings have matured could be catastrophic for the species and the community in which it dominates. Fortunately, in most of these communities some *Podocarpus* shrubs escaped the fires, probably due to the sparse cover of shrubs amongst the rocky scree (Fig. 5). These mature escapees should contribute seed both to the bare surrounding soils and to the Mountain Pygmy Possums that feed on the species.

Although not recorded in the current study, *Celmisia costiniana* is a species that looks likely to be affected in the long term in areas where it was burnt. This species forms large patches, often in areas of late lying snow. It is strongly rhizomic and, intuitively, would be expected to resprout following fire. Many of the large patches of *C. costiniana* we have observed in KNP and on the Bogong High Plains have shown no signs of regeneration from perennating shoots or from seed. The failure of regeneration from seed is not so surprising as plants in these mono-specific patches rarely flower and in years when flowering occurs seed set is commonly very low through endogenous or exogenous (e.g. predation by insect larvae) factors. The bases of burnt plants can now be easily dislodged and there would seem to be little chance that future resprouting will occur. As this species fills, as the overwhelming dominant, an important niche in the alpine landscape, it will be interesting to see what replaces it or if there is a latent seed reserve still awaiting an opportunity for germination.

Table 4. Species apparently advantaged by fire (post-fire frequency more than twice the pre-fire frequency and occurring in at least 4 quadrats post-fire).

Species	f pre-fire	f post-fire
Carex hebes	8	17
**Cirsium vulgare*	0	12
Drabastrum alpestre	2	5
Neopaxia australasica	2	6
Stellaria multiflora	7	15
Viola fuscoviolacea	1	10

Of the species commonly found more frequently after the fire, four were perennials (Table 4). In the case of *Carex hebes* it is possible that it was overlooked in the pre-fire sampling, as many species flowered poorly at that time. *Drabastrum alpestre*, *Neopaxia australasica* and *Stellaria multiflora* all appear to be disturbance-loving and have been found to be frequent colonisers of soil up-heaved by pigs at Nungar Plain in KNP (McDougall & Walsh 2002). *Cirsium vulgare* does seem to have been advantaged by the fire and is now common in many plant communities, especially bogs. It will be worth monitoring its abundance in coming years to determine if it has used the fire to gain a foothold in KNP or if it is simply a transient species. Some species were highly conspicuous after the fire but were not found in additional quadrats by us. For example, *Stellaria pungens* was a locally dominant plant following the fire and, when in flower, was one of the most prominent species present in subalpine areas. It was, however, found in as many of our quadrats before the fire as it was after (Appendix), suggesting that its prominence was due to an increase in cover rather than in distribution.

Species of conservation significance

Interestingly, a number of species of conservation significance were encountered post-fire but not recorded before the fires. Within the quadratted areas, these included *Barbarea grayi* (1 site), *Pelargonium helmsii* (1 site) and *Taraxacum aristum* (2 sites). *Wahlenbergia densifolia* (1 site) had been recorded in a few pre-fire quadrats, but also appeared in one of the burnt quadrats in which it was previously not recorded. These species were noted more commonly in treeless areas generally (i.e. as well as in quadrats) following the fires. *Chenopodium erosum*, a species not recorded in quadrats, was noted as a common species in burnt shrublands, often in association with *Pelargonium helmsii*. It was especially common between Guthega and Mt Jagungal and extended into the alpine zone (to about 1900 m above sea level). This species was hitherto not recorded for KNP. *Drabastrum alpestre*, a species recorded occasionally in disturbed sites (mainly caused by pig foraging) before the fires, was abundant post-fire. *Pelargonium helmsii* (Fig. 6) and *P. australe* had been rarely collected in the subalpine and alpine areas of KNP before the fire. Both species were found to be locally abundant after the fire. Although these species were indistinguishable in their vegetative state, the leaves of *P. helmsii* were found to have a strong smell when crushed, intensely reminiscent of Coriander (*Coriandrum sativum*). Those of *P. australe* had a more familiar *Pelargonium*-like odour.

The occurrence of alpine or subalpine fire ephemerals is surprising. The longevity of seeds of these species would appear to be measurable in decades, perhaps approaching a century or more. The alternative to this perspective is that the frequency of fires in the alps is currently underestimated. It is possible that relatively small-scale lightning-ignited fires are moderately frequent, perhaps particularly at scattered lightning-prone sites. The scatter of these sites across the landscape may be sufficient to allow the persistence of the fire-ephemerals noted above.

Some species (*Bossiaea* sp. aff. *riparia*, *Hovea* sp. aff. *heterophylla*, *Swainsona monticola*) appeared to have been disadvantaged by the fires, at least in the short term. *Bossiaea* sp. aff. *riparia* is probably simply an obligate seeder and will hopefully return in abundance. *Hovea* sp. aff. *heterophylla* may also be an obligate seeder but many plants were observed to be under stress or dead at the time of the pre-fire sampling, as were plants of many other species, presumably as a result of the drought. The taxonomy of these latter two species is currently under review (I.R. Thompson and J.H. Ross, both National Herbarium of Victoria, pers. comm.). The combination of the drought and severe fire may produce outcomes not expected based on the reproductive ecology of the species alone. Other rare species (e.g. *Rutidosis leiolepis*, *Galium roddii*, *Xerochrysum palustre*) appeared to have been relatively unaffected by the fires within the first year.

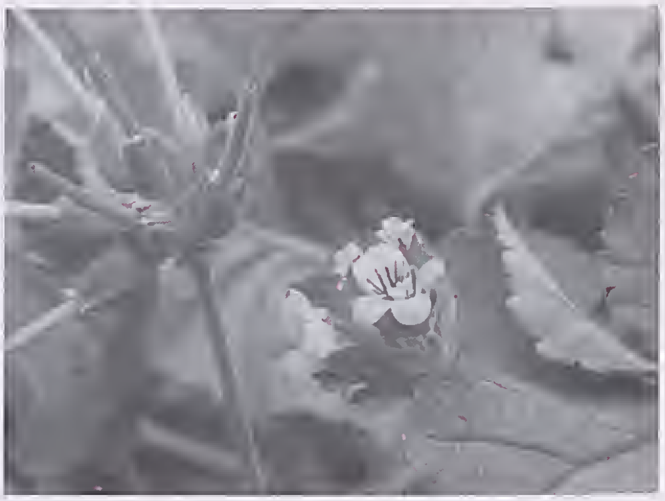

Fig. 6. There were few collections of *Pelargonium helmsii* in NSW prior to the 2003 fire. In December 2003, it was the dominant ground cover in many burnt shrub communities between Mt Blue Cow and Mt Jagungal.

Implications for recovery

It is not possible to predict with great accuracy to what extent and when vegetation might return to pre-fire conditions. The observed recovery of most species suggests that there is little evidence for local extinction, although 24 species noted in quadrats before the fire were not relocated up to 12 months following the fire. A few of these, however, were observed regenerating in sites outside quadrats. The apparent losses may be due to a number of reasons: e.g. our inability to find or identify very young seedlings; seeds requiring more than one year of dormancy post-fire before germination; absence of seeds in soil within the quadrat, but possibly extant in the immediate vicinity etc.

The recovery and performance of all species depends largely on conditions that are experienced in the critical immediate post-germination phase. Extended periods of extreme weather (high/low temperature/precipitation) will result in higher levels of mortality in some species than in others, resulting in a dramatic tilting of the abundance of those species in the mature vegetation relative to its pre-fire state. Even under benign or 'normal' conditions changes are to be anticipated for the foreseeable future. Studies of post-fire recovery of treeless subalpine vegetation in Victoria — at Mt Buffalo (van Rees & Walsh 1985, Wahren & Walsh 2000), and on the Snowy Range (Wahren, Papst & Williams 2001) suggest a trend toward increased shrub frequency over the short- to medium-term in grasslands, open heathlands and closed heathlands. This increase in shrubbiness is attributed to the germination requirements of many shrub species. Studies in many alpine/subalpine areas (e.g. Williams & Ashton 1987b) indicate a need for exposed soil for recruitment of non-resprouting shrubs. These conditions are common and widespread following wildfire. The effects of high temperatures in promoting germination particularly in hard-coated species such as *Asterolasia*, *Bossiaea*, *Grevillea*, *Oxylobium*, *Podolobium* and *Phebalium* further increases their abundance in the post-fire landscape. An eventual return to less shrubby conditions is anticipated as species with limited longevity, such as *Asterolasia trymalioides*, *Grevillea australis*, and *Phebalium squamulosum*, reach the end of their life. On the Bogong High Plains, Victoria, this period has been documented at about 50 years (Wahren et al. 1994) after which other herbaceous species are able to dominate microsites in which they have become established during the moribund phase of the shrubs. At Mt Buffalo, heathland communities had returned to broadly similar floristic and structural composition after 15 years following wildfire whereas grassland sites were still shrubbier after this period (Wahren & Walsh 2000). In both heathlands and grasslands the percentage of bare ground had returned to levels considered satisfactory for adequate soil protection (<5%) after 15 years.

The recovery of bog vegetation is likely be a slower process. The epacrids which are common in wetland communities (e.g. *Epacris celata*, *E. gunnii*, *E. petrophila* and *Richea continentis*), are obligate seed-regenerators, are slow to germinate and early growth rates are quite slow relative to many other species. These are often important structural components of bogs, particularly *Richea continentis*. The rope-rushes *Baloskion australe* and, particularly, *Empodisma minus* are, conversely, rapid resprouters from rootstocks. These plants had appeared only a few weeks after the fires and continued to grow vigorously to the 2003–2004 recordings. Victorian studies cited above recorded a significant and persistent increase in cover of *Empodisma* for 15 years post-fire. The Mt Buffalo study showed a return to pre-fire levels at one site for *Sphagnum cristatum* in this same period but lower than pre-fire levels for *Richea continentis* and higher than pre-fire levels for *Baeckea gunniana* at the same site.

A badly degraded bog on the Bogong High Plains fenced from grazing cattle in 1945 had regenerated so that in 2002 the cover of *Sphagnum* and *Richea continentis* was high, and generally believed to reflect or at least approach conditions in a 'pristine' bog (pers. obs. authors). *Empodisma minus*, although present at the site, was in relatively low abundance. These observations suggest that a period between 15 and 45 years might be required for *Sphagnum*-dominated alpine/subalpine bogs to recover from a disturbed state. Wimbush & Costin (1979) reported that *Sphagnum* bogs were 'nearing the climax stage' under benign conditions 19 years after the cessation of grazing at Gungartan (KNP), but in areas of persistent erosion after grazing no or little recovery of *Sphagnum* had occurred. Their monitoring of the recovering mossbed vegetation showed similar trends to those reported by the Victorian studies i.e. an initial increase then decline of the rushes *Baloskion australe* and *Empodisma minus*, and a slow, but steady increase of 'hygrophilous shrubs' (e.g. *Baeckea* spp., *Epacris* spp.. *Richea continentis*). In areas where *Sphagnum* has been completely lost from a site, unless there is importation of live plant parts (either by fragmentation and movement by water down the catchment, or by human intervention), both the moss and the bogs which are dependent on it for development of permanently moist conditions may become locally extinct.

Management recommendations

In most situations, it is believed that most plant communities will return naturally to their pre-fire condition over a period between a few years and a few decades. Major exceptions will be those communities where the 'keystone' species appear to have been lost at least at a local scale. Principle amongst these are communities that incorporated significant pre-fire biomass of *Sphagnum* (bogs), *Podocarpus lawrencei* (shrublands) and *Celmisia costiniana* (closed herbfields). Consideration might be given to augmenting the recovery of these communities by stabilising exposed ground, and by artificial reintroduction of their dominant species to the sites. Some of this work, if attempted, will be pioneering. Methods for the revegetation of bogs have been developed that include slowing water movement across damaged areas by installation of slow-decomposing barriers and by artificial reintroduction of *Sphagnum* and other dominants. These techniques have been undertaken in both KNP and Victoria with promising results (Brooks & Stoneman1977, McPhee 2003).

Other communities on exposed, steep and/or otherwise unstable sites may be particularly prone to soil (and soil-stored seed) loss, potentially leading to recruitment by opportunistic plants with seeds capable of medium to long-distance dispersal (e.g. *Cirsium vulgare* as noted above, and other daisies, native or exotic) rather than the original occupants. Return to pre-fire conditions on these sites may be slow and involve several stages but as long as colonisation does occur and the colonists are not predominantly exotic, recovery should proceed. Such sites should be monitored to check on the nature of the colonising plants and consideration given to eradication of weeds and re-establishment of the components of the pre-fire communities there.

Future monitoring

We believe that the fires of 2003, while in one sense destructive, have provided a rare opportunity for recruitment of apparently short-lived fire- and/or disturbance-dependent species (e.g. *Barbarea grayi*, *Chenopodium erosum*, *Drabastrum alpestre*, *Pelargonium* spp.) as well as an opportunity to document the recovery of a suite of high-altitude plant communities conventionally believed to have evolved under a regime of very low fire frequency. Potentially informative avenues for future monitoring and/or research are outlined below.

- Using the methods outlined above, continue monitoring all or a representative sample of the 60 pairs of pre- and post-fire quadrats investigated in this study. Based on responses following fire in broadly similar vegetation in Victorian, appropriate periods of monitoring would be 1, 2, 5, 10, 15 and 20 years post-fire.
- Monitoring populations of the rare and apparently short-lived *Barbarea grayi*, *Chenopodium erosum*, *Drabastrum alpestre*, *Pelargonium helmsii* to ascertain the longevity and phenology of these poorly understood species.
- Undertaking landscape-scale monitoring using satellite imagery and/or aerial photography. This method should help to indicate return to vegetated cover, if not the composition of recovering vegetation. Sites that continue to register low vegetated cover should be targeted for closer on-ground monitoring.

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Appendix: Frequency of all species recorded in 60 quadrats pre- and post-fire with their mode of regeneration (where observed) and record of flowering.

Records where the presence of a species in a quadrat was attributable solely to escape from the fire rather than regeneration are shown in parentheses. [a] indicates an observation for mode of regeneration or flowering in a species observed outside the quadrats. * indicates an introduced species.

	Frequency		Regeneration		
Taxon	Pre-fire	Post-fire	Seed	Resprout	Flower
Antherieaceae					
Arthropodium milleflorum	8	11		+	+
Caesia alpina	7	4		+	+
Apiaceae					
Aciphylla simplicifolia	21	26	+	+	+
Gingidia harveyana	1	1		+	
Hydrocotyle algida	7	7		+	
Hydrocotyle sibthorpioides	4	5		+	
Hydrocotyle tripartita	1	1	+		
Oreomyrrhis argentea	13	12	+	+	
Oreomyrrhis ciliata	13	3	+	+[a]	+
Oreomyrrhis eriopoda	9	6	+	+	+
Asphodelaceae					
Bulbine bulbosa	4	3		+	+
Asteliaceae					
Astelia alpina var. *novae-hollandiae*	1	1		+	
Astelia psychrocharis	3	3		+	
Asteraceae					
Argyrotegium poliochlorum	1		+		
Brachyscome aculeata	8	8		+	+
Brachyscome decipiens	14	21		+	+
Brachyscome obovata	7	8		+	+
Brachyscome radicans		1		+	
Brachyscome rigidula	2	1		+	
Brachyscome scapigera	13	15		+	+
Brachyscome spathulata	10	9		+	+
Calotis glandulosa	1	1		+	+
Cassinia monticola	26	20	+	+	
Cassinia sp. 'Cave Creek'		1		+	
Celmisia pugioniformis	14	21		+	+
Celmisia sp. aff. *pugioniformis* (bogs)				+[a]	
Celmisia tomentella	3	3		+	
Chrysocephalum semipapposum	1	1		+	+
**Cirsium vulgare*		12	+		
**Conyza bonariensis*		1	+		+
Cotula alpina	3			+	
Craspedia aurantia	8	8		+	+
Craspedia coolaminica	14	15		+	+
Craspedia crocata	7	8		+	+
Craspedia jamesii	20	20		+	+
Craspedia lamicola	1	1		+	
Craspedia sp. aff. *crocata* 'Bogong Swamp'	4	3		+	+
**Crepis capillaris*	2	3	+	+	+
Erigeron bellidioides	6	7		+	+
Erigeron nitidus	4	4		+	+
Erigeron paludicola	2			+	
Euchiton argentifolius	2		+		
Euchiton collinus	1				
Euchiton involucratus		1	+		
Helichrysum rutidolepis	5	8		+	
Helichrysum scorpioides	3	3		+	
**Hypochaeris radicata*	20	19	+	+	
**Lactuca serriola*		1	+		
Lagenifera stipitata	1				
Leptorhynchos squamatus	19	19		+	
Leucochrysum albicans subsp. *alpinum*	3	3		+	
Microseris lanceolata	20	18		+	+

Olearia algida	7	2(2)	+		
Olearia brevipedunculata	2	3		+	
Olearia myrsinoides	2	1		+	
Olearia phlogopappa subsp. *flavescens*	6	6		+	
Olearia ramulosa		1	+		
Ozothamnus hookeri	2				
Ozothamnus secundiflorus	4	3	+	+	
Picris angustifolia subsp. *merxmuelleri*		3	+		
Podolepis hieracioides	2	4		+	+
Podolepis jaceoides	4	4		+	+
Podolepis robusta	2	3		+	+
Rhodanthe anthemoides	8	6		+	+
Rutidosis leiolepis	1	1		+	
Senecio gunnii	13	15	+	+	
Senecio pinnatifolius var. *pleiocephalus*	14	11		+	+
Senecio extensus	4	4		+	
Senecio lageniformis	1			+	+
Senecio longipilus		1		+	+
Solenogyne gunnii	2				
Taraxacum aristum		2		+	+
**Taraxacum officinale* spp. agg.	8	5	+	+	+
**Tragopogon dubius*	4	3	+	+	
Vittadinia cuneata	1	1			
Xerochrysum palustre	1	1		+	+
Xerochrysum subundulatum	11	10		+	+
Xerochrysum viscosum	1	1		+	+
Blechnaceae					
Blechnum penna-marina	1	1(1)			
Boraginaceae					
Myosotis australis		1	+		
**Myosotis caespitosa*		1	+		
**Myosotis discolor*		2	+		+
Brassicaceae					
Barbarea grayi		1	+		+
Cardamine astoniae	7	4		+	+
Cardamine lilacina	12	7	+	+	+
Cardamine papillata	1	3	+		+
Drabastrum alpestre	2	5	+		+
**Rorippa palustris*	1	2	+		+
Campanulaceae					
Wahlenbergia ceracea	1	1	+		
Wahlenbergia densifolia		1		+	
Caryophyllaceae					
**Cerastium glomeratum*		5	+		+
**Cerastium vulgare*	7	8	+		+
**Petrorhagia nanteuilii*		1	+		+
Scleranthus biflorus	25	6(2)	+	+	
Scleranthus fascicularis	4	4(1)			
Scleranthus singuliflorus	1	1		+	
Stellaria angustifolia	5	7	+	+	+
Stellaria multiflora	7	15	+		+
Stellaria pungens	17	16	+	+	+
Chenopodiaceae					
Chenopodium erosum			+[a]		
Clusiaceae					
Hypericum japonicum	8	2		+	
Convolvulaceae					
Convolvulus erubescens sens. lat.	1	1		+	
Dichondra repens	1		+		
Crassulaceae					
Crassula peduncularis		1	+		+
Crassula sieberiana	1	1	+	+	

**Sedum acre*	1				
Cyperaceae					
Carex appressa	5	3		+	
Carex blakei	2	3		+	+
Carex breviculmis	36	32	+	+	+
Carex capillacea	2	1		+	+
Carex chlorantha	2	2		+	+
Carex gaudichaudiana	20	19		+	+
Carex hebes	8	17		+	+
Carex incomitata	1	1		+	
Carex jackiana	5	7		+	
Carpha nivicola	1			+	
Isolepis aucklandica	1	2	+		+
Isolepis crassiuscula	2	4	+		
Isolepis habra		1			+
Oreobolus distichus	3	1		+	
Oreobolus oxycarpus	1	1		+	
Dryopteridaceae					
Polystichum proliferum	1	1		+	
Epacridaceae					
Epacris celata	3				
Epacris gunnii	19	2	+		
Epacris paludosa	9	6(1)		+	
Epacris petrophila	7	1(1)			
Leucopogon fraseri	1	1		+	
Leucopogon hookeri	18	21		+	
Leucopogon montanus	1	1		+	
Richea continentis	6	2(2)			
Euphorbiaceae					
Poranthera microphylla	14	18	+	+	+
Fabaceae					
Bossiaea foliosa	15	12	+	+	
Bossiaea sp. aff. *riparia*	1				
Daviesia ulicifolia	2	1		+	
Dillwynia palustris	2	1	+		
Hovea montana	19	16	+	+	
Hovea sp. aff. *heterophylla*	2	1	+	+	
Oxylobium ellipticum	10	5	+	+	
Podolobium alpestre	2	2	+	+	
Pultenaea fasciculata	4	1		+	
Pultenaea polifolia	1				
Swainsona monticola	1				
**Trifolium arvense*		1	+		
**Trifolium campestre*		3	+		+
**Trifolium dubium*	1	1	+		
**Trifolium repens*	9	8	+		+
Gentianaceae					
Chionogentias muelleriana subsp. *alpestris*	1		+	+	+
Geraniaceae					
Geranium antrorsum	13	19	+	+	+
Geranium potentilloides	9	15	+	+	+
Geranium sp 'alpine swamps'	1	1	+		
Pelargonium australe			+[a]		+
Pelargonium helmsii		1	+		+
Goodeniaceae					
Goodenia hederacea subsp. *alpestris*	4	4	+	+	
Scaevola hookeri	1	1	+		
Velleia montana	2	2		+	
Haloragaceae					
Gonocarpus micranthus	7	12(1)	+		
Gonocarpus montanus	3	2	+		
Myriophyllum pedunculatum	2	2	+	+	+

Myriophyllum variifolium	1	1(1)			
Juncaceae					
Juncus alexandri		1			
Juncus brevibracteus	3	2		+	
**Juncus effusus*	1	1		+	
Juncus falcatus	3	1		+	
Juncus sandwithii		1			
Luzula alpestris	3	3		+	+
Luzula flaccida	13	6		+	+
Luzula modesta	19	19	+	+	+
Luzula novae-cambriae	3	1		+	
Lamiaceae					
Ajuga australis	6	10		+	+
Prostanthera cuneata	1				
Westringia lucida	4	3	+		
Lentibulariaceae					
Utricularia monanthos	1	2		+	+
Linaceae					
Linum marginale	10	5	+	+	
Lobeliaceae					
Pratia pedunculata	3	6		+	+
Pratia surrepens		2		+	+
Mimosaceae					
Acacia alpina	3	1	+		
Myrtaceae					
Baeckea gunniana	11	8(1)		+	
Baeckea utilis	1	1		+	
Callistemon pityoides	1	1		+	
Eucalyptus lacrimans	2	2		+	
Eucalyptus niphophila	1	1		+	
Kunzea muelleri	14	5(1)		+	
Leptospermum myrtifolium	2	2(1)		+	
Onagraceae					
Epilobium billardiereanum	12	8		+	+
Epilobium curtisiae	2	2	+	+	
Epilobium gunnianum	9	8		+	+
Orchidaceae					
Caladenia alpina		1		+	
Diuris monticola	2	1		+	+
Prasophyllum sphacelatum	5	2		+	+
Thelymitra cyanea	1	3		+	+
Oxalidaceae					
Oxalis exilis	2				
Phormiaceae					
Herpolirion novae-zelandiae	1	1		+	
Pittosporaceae					
Rhytidosporum alpinum	6	4		+	
Plantaginaceae					
Plantago antarctica	4	3		+	
Plantago euryphylla	3	5		+	+
Plantago varia		1			
Poaceae					
**Agrostis capillaris*		1			
Agrostis venusta	1				
**Aira elegantissima*	1	3	+		+
**Anthoxanthum odoratum*	6	7		+	+
Australopyrum velutinum	2	3		+	+
Austrodanthonia eriantha	1	1		+	+
Austrodanthonia laevis	1	2		+	+
Austrodanthonia oreophila	2	3		+	+

Austrodanthonia penicillata	1	2		+	+
Austrodanthonia pilosa		1		+	
Austrofestuca hookeriana		2		+	+
Austrostipa nivicola	7	6	+	+	
**Bromus hordeaceus*		1	+		
Deyeuxia crassiuscula		1		+	
Deyeuxia monticola	2	2		+	+
Dichelachne crinita		4	+		+
Elymus scaber	4	7		+	+
Festuca asperula	5	4		+	+
Festuca muelleri	4	1	+		+
**Festuca rubra* subsp. *rubra*		1		+	+
Hierochloe redolens	1	4		+	+
**Holcus lanatus*	1		+		
Lachnagrostis aemula		1	+		
Microlaena stipoides		1		+	
Poa clivicola	13	13	+	+	
Poa costiniana	29	31	+	+	+
Poa ensiformis	1	1		+	
Poa fawcettiae	6	6	+	+	+
Poa hiemata	23	23	+	+	+
Poa hookeri	3	3	+	+	+
Poa labillardierei var. *labillardierei*	1	2		+	
Poa petrophila	2	1		+	
Poa phillipsiana	9	9	+	+	+
**Poa pratensis*	2	3		+	
Poa saxicola	2	1		+	+
Rytidosperma nudiflorum	3	2		+	+
Themeda australis	5	4		+	
Trisetum spicatum	12	14		+	+
**Vulpia bromoides*	3	4	+		+
Podocarpaceae					
Podocarpus lawrencei	1	1(1)	+[a]		
Polygalaceae					
Comesperma retusum	2	1	+		
Polygonaceae					
**Acetosella vulgaris*	30	41	+	+	+
Muehlenbeckia axillaris	1	1		+	
**Polygonum arenastrum*		1	+		+
**Rumex conglomeratus*	1	1		+	
Portulacaceae					
Neopaxia australasica	2	6	+	+	+
Proteaceae					
Grevillea australis	21	6	+		
Grevillea lanigera	1	1	+		
Hakea microcarpa	22	18		+	
Orites lancifolia	6	5		+	
Persoonia chamaepeuce	2	1		+	
Ranunculaceae					
Ranunculus collinus	1				
Ranunculus graniticola	30	24	+	+	+
Ranunculus millanii	6	3(1)		+	+
Ranunculus pimpinellifolius	4	4	+		+
Restionaceae					
Baloskion australe	10	7		+	
Empodisma minus	20	22	+	+	
Rhamnaceae					
Cryptandra amara	2	1		+	
Rosaceae					
Acaena echinata	4	5		+	+
Acaena novae-zelandiae	13	8		+	+
Acaena ovina		1		+	

***Aphanes arvensis**		2	+		+
Geum urbanum		1		+	
**Potentilla recta*		1	+		+
**Rosa rubiginosa*	1	1			
Rubiaceae					
Asperula conferta		1		+	
Asperula gunnii	37	48	+	+	+
Asperula pusilla		2	+		
Asperula scoparia	3	3	+	+	
Galium roddii		1(1)			
Nertera granadensis	1	1		+	
Rutaceae					
Asterolasia trymalioides	2	1	+		
Nematolepis ovatifolia	1				
Phebalium squamulosum subsp. *alpinum*	8	7	+		
Salicaceae					
**Salix cinerea*		1	+		
Scrophulariaceae					
Derwentia perfoliata	1	1	+		
Euphrasia collina subsp. *diversicolor*	1	1		+	
Euphrasia collina subsp. *paludosa*	12	3		+	+
Gratiola nana	1	1(1)			
Limosella australis		1	+		+
**Linaria vulgaris*		1	+		+
**Verbascum virgatum*	1	1(1)			
**Veronica arvensis*		1	+		
Veronica gracilis		5		+	
Stackhousiaceae					
Stackhousia monogyna	1	1			
Stylidiaceae					
Stylidium montanum	20	17	+	+	+
Thymelaeaceae					
Pimelea alpina	3	1	+	+	
Pimelea biflora	7	2(1)		+	
Pimelea bracteata	2	2	+	+	
Pimelea linifolia subsp. *caesia*	20	17	+	+	+
Pimelea pauciflora	1				
Tremandraceae					
Tetratheca bauerifolia	1	1		+	
Violaceae					
Melicytis dentatus	8	3		+	
**Viola arvensis*	1		+	+	+
Viola betonicifolia	16	18		+	+
Viola fuscoviolacea	1	10	+	+	+
Winteraceae					
Tasmannia xerophila subsp. *xerophila*	2	1		+	

Vegetation of Basket Swamp National Park, Northern Tablelands, New South Wales

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Abstract: The vegetation of Basket Swamp National Park (2820 ha), 30 km north east of Tenterfield (28°54'S, 152°09'E) in the Tenterfield Shire, in the Northern Tablelands Bioregion NSW, is described. Seven vegetation communities are mapped based on survey of plots, subsequent ground-truthing, air photo interpretation and substrate.

Communities described are: (1) *Eucalyptus campanulata* (Blackbutt) – *Eucalyptus cameronii* (Diehard Stringybark) Open Forests, (2) *Eucalyptus campanulata* (Blackbutt) – *Eucalyptus cameronii* (Diehard Stringybark) Grassy Open Forests, (3) *Leptospermum trinervium* (Tea-tree) – *Leptospermum polygalifolium* subsp. *transmontanum* (Creek Tea-tree) Riparian Scrub, (4) *Leptospermum trinervium* (Tea-tree) – *Kunzea obovata* (Pink Kunzea) – *Leptospermum novae-angliae* (New England Tea-tree) Heaths & Shrublands, (5) *Ceratopetalum apetalum* (Coachwood) – *Lophostemon confertus* (Brush Box) Closed Forest, (6) *Eucalyptus obliqua* (Messmate) – *Eucalyptus campanulata* (Blackbutt) Tall Open Forests, and (7) *Baeckea omissa* (Baeckea) – *Baloskion stenocoleum* (Sedge) Heathy Sedgelands.

All but two communities (3 & 7) were considered adequately reserved locally, no listed endangered or vulnerable communities were found. Thirty-six taxa were considered to be of conservation significance of which two are listed as vulnerable on Schedule 2 of the NSW *TSC Act*. A further nine have been reported under the RoTAP criteria.

***Cunninghamia* (2004) 8(4): 453–466**

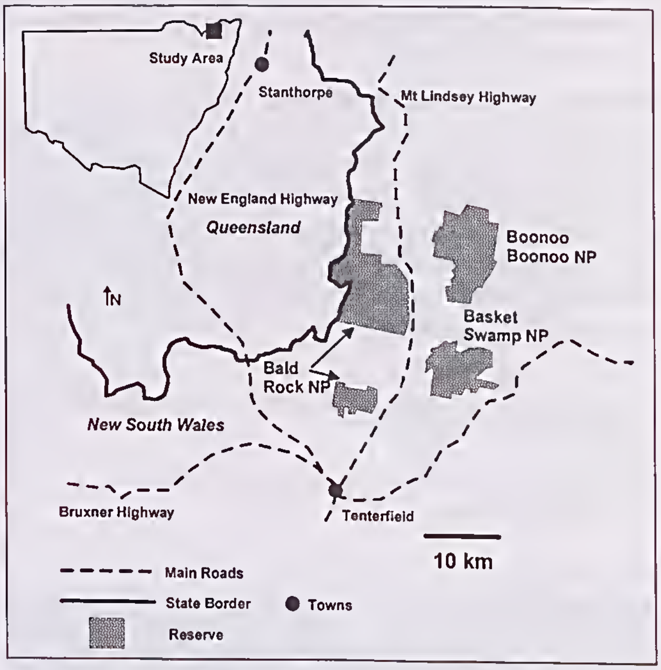

Fig. 1. Location of Basket Swamp National Park, and nearby conservation areas in northeastern NSW.

Introduction

Basket Swamp National Park is located approximately 30 km north east of Tenterfield and 10 km west of the Mount Lindsay Highway (28°54'S, 152°09'E) (Fig. 1). Basket Swamp National Park lies within the New England Tablelands Bioregion, the Northern Tablelands Botanical division and the local government areas of the Tenterfield Shire and the County of Clive. The Park encompasses 2 820 ha, which includes part of the former Boonoo State Forest and was gazetted in 1999. The reserve is bounded on three sides by vegetated private freehold land and on the north by State Forest.

Climate

Overall, rainfall ranges from 1300–1400 mm annually within the region. Rain falls mostly in the summer (60–70%) due to a predominantly easterly airflow from the Pacific Ocean and the effects of tropical cyclones from the north east. Snow occurs occasionally at higher altitudes and frosts are frequent in winter. Mean annual temperatures are greatest within the gorge areas (16–17°C) but are at there lowest on the higher parts of the reserve (11–12°C). Dry southwest to westerly winds predominate in the winter months.

Landform

Apart from the larger landform features such as Bornhardts (larger rock outcrops) the landform is generally undulating to hilly with wide flat valleys. These valleys usually contain broad meandering swampy ground fed by the high runoff from outcrops and ridges. Elevations vary from a maximum of 1163 m (ASL) at Timbarra Lookout to 700 m (ASL) in the lower parts of the Cataract River gorge in the east. Slopes within the gorge areas can be steep.

Drainage is predominantly to the east. Three named channels are associated with the reserve and include Basket Swamp Creek, which flows from the large Basket Swamp, Wellingtons Creek that flows into Basket Swamp Creek and the Cataract River all of which form part of the eastern boundary.

Geology

Basket Swamp National Park lies within the New England Orogen. The New England Orogen (NEO), of the New England Fold Belt (NEFB), is a belt of complex geology interpreted to be a tectonic collage of a number of terranes that amalgamated with, and accreted to the eastern margin of Gondwana during the late Paleozoic-early Mesozoic (Flood & Fergusson 1984, Flood & Aitchison 1993).

Methods

Vascular plants were scored using the Braun-Blanquet (1982) six point cover abundance scale from 40, 20 × 50 m quadrats. Quadrats were placed using a stratified random method using altitude, aspect and physiography (crest & upper slope, lower slope & flats, open depressions). The survey was conducted during 5 days in January 2002 when seasonal rainfall was below average.

Analyses and data exploration were performed using options available in the PATN Analysis Package (Belbin 1995a, b). For final presentation of results all species and their relative cover scores were used and the analysis performed using Kulczynski association measure which is recommended for ecological applications (Belbin 1995a, b) along with flexible Unweighted Pair Group arithmetic Averaging (UPGMA) and the default PATN settings.

Delineation of community boundaries in Figure 3 was based on the location of sites and their position within the multivariate analysis, air photograph interpretation, substrate and ground-truthing. The vegetation map is based on a 1:25 000 scale. Structural names follow Specht et al. (1995) and are based on the most consistent uppermost stratum. Nomenclature follows that of Harden (1992–2002) except where recent changes have been made.

Results

Seven communities were recognised at the dissimilarity measure of 0.8. A summary of the community relationships is given in the dendrogram and map (Figs 2 & 3). A total of 430 vascular plant taxa were recorded from 40 sites and opportunistic collections. Three hundred and thirty five taxa were recorded within sites and an additional 95 were recorded opportunistically or from previous records. The number of taxa captured represents about 7% of the total NSW flora and about 20% of the Northern Tablelands flora.

The 430 taxa occurred in 105 families and 269 genera. The families with the greatest number of taxa are: Fabaceae (42), Poaceae (34), Asteraceae (34), Myrtaceae (30), Cyperaceae (20), Epacridaceae (13), Proteaceae (12), Dilleniaceae (9), and Apiaceae (8). The richest genera are: *Acacia* (14), *Eucalyptus* (14), *Hibbertia* (8), *Leptospermum* (6), *Juncus* (5), *Pultenaea* (5), and *Wahlenbergia* (5). During the survey 15 taxa (3.6%) were found to be exotic in origin.

Vegetation communities

The structure of communities within Basket Swamp National Park varies, with most showing a woodland or forest structure. In more protected sites tall open and closed forests occur, while heaths and open woodlands develop in areas of impeded drainage. Some specialised communities as rock outcrop shrublands and *Sphagnum* swamps are notable. A shrub component within forests and woodlands is often present and can form one or two layers. In some instances, this is poorly developed and grasses dominate. The order of names reflects the importance of each species in terms of there cover and fidelity to each community. A summary of relevant statistics for each community are presented in Table 1. Extreme values are given in brackets within the following descriptions of communities.

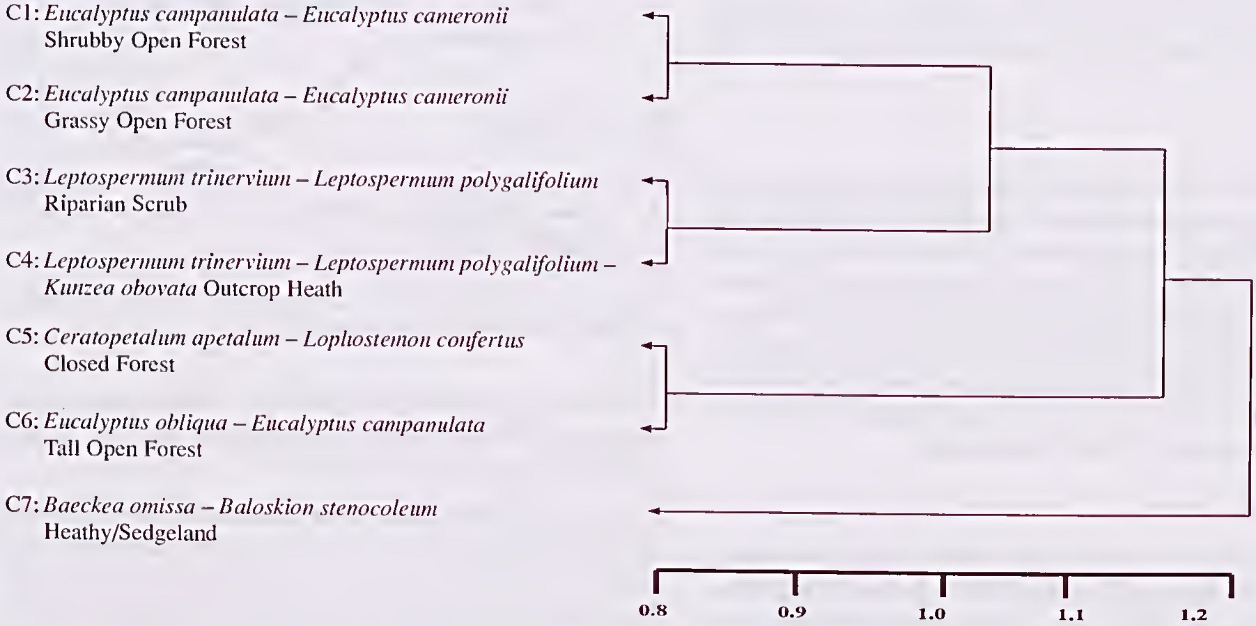
C1: *Eucalyptus campanulata – Eucalyptus cameronii* Shrubby Open Forest
C2: *Eucalyptus campanulata – Eucalyptus cameronii* Grassy Open Forest
C3: *Leptospermum trinervium – Leptospermum polygalifolium* Riparian Scrub
C4: *Leptospermum trinervium – Leptospermum polygalifolium – Kunzea obovata* Outcrop Heath
C5: *Ceratopetalum apetalum – Lophostemon confertus* Closed Forest
C6: *Eucalyptus obliqua – Eucalyptus campanulata* Tall Open Forest
C7: *Baeckea omissa – Baloskion stenocoleum* Heathy/Sedgeland
0.8
0.9
1.0
1.1
1.2

Fig. 2. Summary dendrogram of full dataset of sites using Kulcznski association and flexible UPGA fusion strategy.

Table 1: Selected attributes of the eleven defined communities in Basket Swamp National Park.

Community	No. of sites	Richness per 400 m² (average)	No. of species	No. of introduced species	Proportion of reserve	No. ha
C1: *Eucalyptus campanulata – Eucalyptus cameronii* Shrubby Open Forest & Woodland	13	32–45 (39.5)	152	2	55%	1676
C2: *Eucalyptus campanulata – Eucalyptus cameronii* Grassy Open Forest	12	28–55 (41)	152	4	34.7%	1059
C3: *Leptospermum trinervium – Leptospermum polygalifolium* Riparian Scrub	1	78	78	1	0.3%	11
C4: *Leptospermum trinervium – Kunzea obovata* Outcrop Heath & Shrubland	5	19–43 (28)	79	0	2%	61
C5: *Ceratopetalum – Lophostemon confertus* Closed Forest	3	24–43 (35)	71	1	1.3%	39
C6: *Eucalyptus obliqua – Eucalyptus campanulata* Tall Open Forest	1	35	35	0	0.4%	11
C7: *Baeckea omissa – Baloskion stenocoleum* Heathy/Sedgeland	5	22–45 (31.5)	83	3	6.2%	190

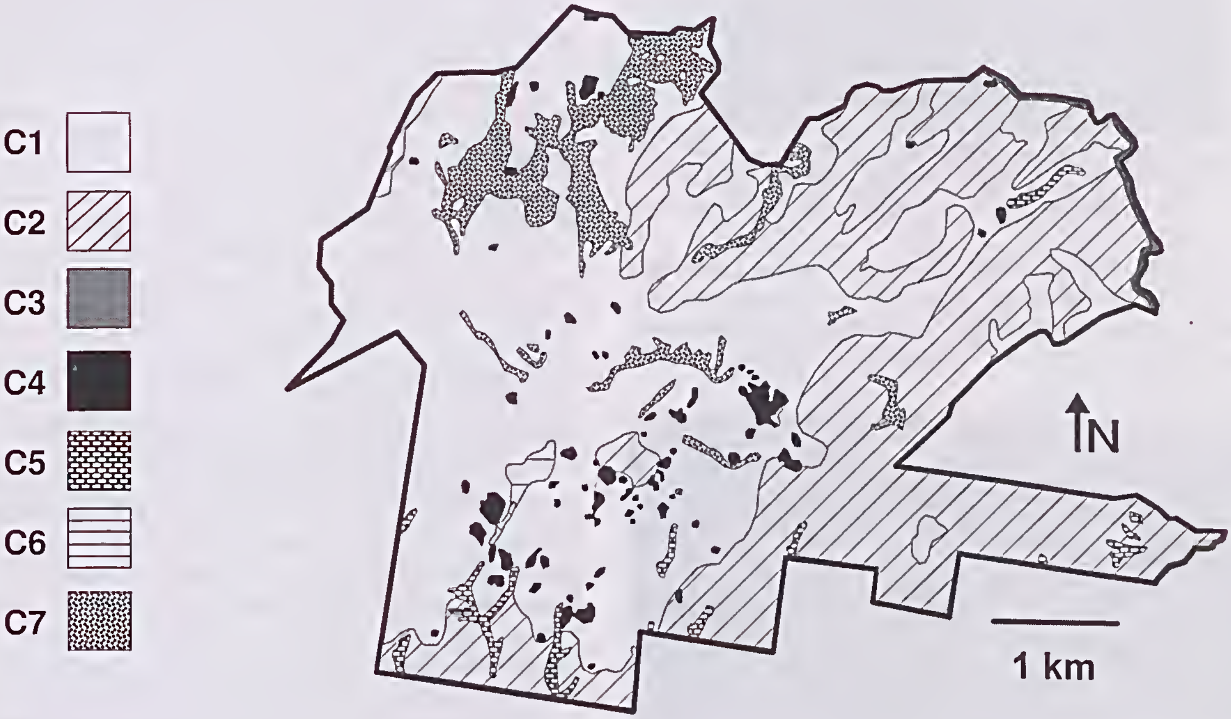

Fig. 3. Map of vegetation communities for Basket Swamp National Park.

Community 1: *Eucalyptus campanulata* (Eastern New England Blackbutt) – *Eucalyptus cameronii* (Diehard Stringybark) – *Eucalyptus laevopinea* (Silvertop Stringybark) Shrubby Open Forest and Woodland

Environmental relationships: found on deep or rarely shallow, well-drained soils that are commonly grey brown loamy coarse sand. In a variety topographic positions from flats to upper slopes and crests.

Structure: open forest to woodland. Tree layer: (10–) 25–35 m tall; (10–) 20–30 (–35)% cover. Tall shrub layer: 3–8 m tall; 10-30 (–50)% cover. Low shrub layer, usually absent: 1–3 m tall; (10–) 20–50 (–80)% cover when present. Understorey layer: < 1 m tall; 20–70% cover.

Trees: *Eucalyptus campanulata, Eucalyptus cameronii, Allocasuarina littoralis, Banksia integrifolia, Eucalyptus laevopinea, Eucalyptus williamsiana, Eucalyptus radiata* subsp. *sejuncta, Eucalyptus notabilis, Eucalyptus acaciiformis, Eucalyptus brunnea.*

Community 1 *Eucalyptus campanulata* and *Eucalyptus cameronii* Shrubby Open Forest and Woodland.

Shrubs: *Petrophile canescens, Podolobium ilicifolium, Monotoca scoparia, Persoonia sericea, Leucopogon lanceolatus, Banksia cunninghamii, Xanthorrhoea glauca, Leptospermum trinervium, Persoonia fastigiata, Lomatia silaifolia, Acacia obtusifolia, Notelaea ovata, Hibbertia villosa, Daviesia elliptica, Boronia microphylla, Amperea xiphoclada, Acrotriche aggregata, Acacia myrtifolia, Acacia ulicifolia, Dillwynia phylicoides, Pultenaea daphnoides, Elaeocarpus reticulatus, Acacia floribunda, Hibbertia obtusifolia, Hakea eriantha, Exocarpos cupressiformis, Epacris microphylla, Boronia algida.*

Climbers & trailers: *Smilax australis, Hardenbergia violacea, Cassytha pubescens, Desmodium varians, Billardiera scandens, Morinda jasminoides, Eustrephus latifolius, Dockrillia pugioniformis, Desmodium rhytidophyllum, Davallia solida.*

Ground cover: *Entolasia stricta, Patersonia glabrata, Themeda triandra, Lepidosperma laterale, Platysace lanceolata, Goodenia hederacea, Bossiaea neo-anglica, Pteridium esculentum, Pomax umbellata, Gonocarpus tetragynus, Dianella revoluta, Austrostipa rudis, Poa sieberiana, Gonocarpus oreophilus, Dichelachne micrantha, Dianella caerulea, Stylidium graminifolium, Patersonia sericea, Imperata cylindrica, Schoenus melanostachys, Austrodanthonia racemosa, Lomandra filiformis, Joycea pallida, Deyeuxia parviseta, Austrostipa scabra.*

Introduced taxa: *Hypochaeris radicata, Hypochaeris glabra.*

Variability: this assemblage intergrades considerably with Community 2 which it shares many of the overstorey dominants. The most distinguishing features of this assemblage are the dominance of shrubs in the understorey. There is much variability in shrub density (10–80% cover).

Conservation status: similar assemblages are reserved within Bald Rock & Boonoo NPs where 2811 ha have been mapped (Hunter 1999), additionally Western Washpool NP has an additional 8070 ha mapped (Hunter 2000b). Well reserved with potentially over 12000 ha reserved locally.

Community 2 *Eucalyptus campanulata* and *Eucalyptus cameronii* Grassy Open Forest.

Community 2: *Eucalyptus campanulata* (Eastern New England Blackbutt) – *Eucalyptus cameronii* (Diehard Stringybark) – *Eucalyptus brunnea* (Brown Gum) Grassy Open Forest

Environmental relationships: occurring on deep or shallow well drained to moist soils that are grey brown to chocolate brown and loamy coarse sand to sandy loam. Usually on mid slopes but also found other topographic positions.

Structure: tall open forest to woodland. Tree layer: 20–35 (–40) m tall; (10–) 20–35% cover. Tall shrub layer: (4–) 10–15 (–20) tall; 10–20 (–70)% cover, often absent. Low shrub layer: 1–5 m tall; 10–20 (–30)% cover, sometimes absent. Understorey layer: < 1 m tall; 30–90% cover.

Trees: *Eucalyptus campanulata, Eucalyptus cameronii, Eucalyptus brunnea, Banksia integrifolia, Allocasuarina littoralis, Eucalyptus saligna, Angophora subvelutina, Allocasuarina torulosa, Wilkiea huegeliana, Eucalyptus obliqua, Eucalyptus notabilis, Eucalyptus caliginosa, Acacia melanoxylon.*

Shrubs: *Leucopogon lanceolatus* subsp. *lanceolatus, Persoonia sericea, Podolobium ilicifolium, Trochocarpa laurina, Hibbertia obtusifolia, Acacia obtusifolia, Elaeocarpus reticulatus, Amperea xiphoclada, Acrotriche aggregata, Lomatia silaifolia, Indigofera australis, Pultenaea villosa, Polyscias sambucifolia, Maytenus silvestris, Hibbertia villosa, Hakea florulenta, Hakea eriantha, Acacia myrtifolia, Acacia floribunda, Acacia filicifolia, Acacia falciformis*

Climbers & trailers: *Hardenbergia violacea, Smilax australis, Desmodium varians, Glycine clandestina, Eustrephus latifolius, Billardiera scandens, Hibbertia scandens, Desmodium rhytidophyllum, Rubus parvifolius, Glycine tabacina, Pandorea pandorana, Morinda jasminoides, Kennedia rubicunda, Geitonoplesium cymosum, Cassytha pubescens.*

Ground cover: *Themeda triandra, Imperata cylindrica, Poa sieberiana, Pteridium esculentum, Gonocarpus oreophilus, Sorghum leiocladum, Entolasia stricta, Gonocarpus tetragynus, Dianella revoluta, Schoenus melanostachys, Calochlaena dubia, Viola betonicifolia, Lepidosperma laterale, Austrodanthonia racemosa, Lomandra longifolia, Dianella caerulea, Poranthera microphylla, Platysace lanceolata, Patersonia glabrata, Goodenia hederacea, Deyeuxia parviseta, Stylidium graminifolium, Pratia purpurascens, Opercularia diphylla, Lomandra multiflora, Entolasia marginata, Brachsycome nova-anglica, Microlaena stipoides, Helichrysum scorpioides, Vernonia cinerea, Thysanotus tuberosus, Senecio diaschides, Lomandra confertifolia, Gahnia aspera, Dichelachne micrantha, Lycopodiella cernua, Helichrysum elatum, Dipodium variegatum, Baloskion stenocoleum.*

Introduced taxa: *Hypochaeris radicata, Conyza albida, Axonopus affinis, Picris hieracioides.*

Variability: though widespread this community is fairly uniform however at times the shrub component may be more prominent and include legumes such as *Podolobium* or *Acacia* that have germinated en-mass due to recent fires that heated the soil sufficiently to germinate seeds. Although shrubs may be common in some areas the understorey is discernibly grassy, sometimes with dense *Imperata* if fire frequencies have been high. This community intergrades considerably with Community 1.

Conservation status: similar assemblages have been described in Bald Rock and Boonoo Boonoo NPs (Hunter 1999) and Western Washpool & Capoompeta NPs (Hunter 2000b) where 6417 ha and 8460 ha have been mapped. Adequately reserved locally with potentially over 16000 ha in conservation.

Community 3: *Leptospermum trinervium* (Tea-tree) – *Leptospermum polygalifolium* subsp. *transmontanum* (Creek Tea-tree) Riparian Scrub

Environmental relationships: restricted to the rocky creek beds.

Structure: heath and shrubland. Tree layer: 10–20 m tall; 5–15% cover, usually absent. Tall shrub layer: 3–12 tall; 10–50% cover, sometimes absent. Low shrub layer: 1–2 m tall; 10–50% cover. Understorey layer: < 1 m tall; 10–30% cover.

Trees: *Allocasuarina torulosa, Eucalyptus campanulata, Eucalyptus brunnea, Banksia integrifolia, Allocasuarina littoralis.*

Shrubs: *Leptospermum trinervium, Epacris obtusifolia, Calytrix tetragona, Pultenaea villosa, Leucopogon neoanglicus, Leptospermum polygalifolium* subsp. *transmontanum, Hibbertia acicularis, Callistemon pallidus, Baeckea omissa, Acacia venulosa, Acacia fimbriata, Zieria fraseri, Xanthorrhoea glauca, Prostanthera* sp. *B,*

Community 3 *Leptospermum trinervium* and *Leptospermum polygalifolium* Riparian Scrub.

Pomaderris lanigera, Pomaderris argyrophylla, Pimelea linifolia, Petrophile canescens, Persoonia sericea, Persoonia oleoides, Persoonia fastigata, Lomatia silaifolia, Hovea pedunculata, Hibbertia villosa, Exocarpus cupressiformis, Dillwynia sieberi, Correa reflexa, Coprosma quadrifida, Bauera rubioides, Banksia cunninghamii, Acrotriche aggregata, Acacia ulicifolia, Acacia floribunda, Acacia filicifolia.

Climbers & trailers: *Cassytha pubescens.*

Ground cover: *Themeda triandra, Xyris operculata, Schoenus melanostachys, Rhynchospora brownii, Panicum simile, Lomandra longifolia, Lomandra confertifolia, Lepyrodia anarthria, Austrostipa rudis, Actinotus helianthi, Wahlenbergia planiflora, Utricularia dichotoma, Triglochin multifructum, Tricoryne elatior, Thysanotus tuberosus, Schoenus apogon, Pteridium esculentum, Poa sieberiana, Patersonia sericea, Patersonia glabrata, Lomandra multiflora, Lepidosperma limicola, Juncus sandwithii, Juncus bufonius, Hypericum japonicum, Hypericum gramineum, Goodenia hederacea, Gonocarpus oreophilus, Gonocarpus micranthus, Gleichenia dicarpa, Drosera spatulata, Digitaria ramularis, Dianella revoluta, Centrolepis fascicularis, Brachyscome stuartii, Austrodanthonia eriantha.*

Introduced taxa: *Hypochaeris radicata.*

Variability: this community is by nature linear with a great edge to area ratio and even common dominants may be absent often due to the great variability in substrate and depth of soil giving a rather variable structure. This assemblage is highly stochastic and most species will have a low constance. The structure also is variable and in places will be densely shrubby and in others shrubs are only a minor component.

Conservation status: Benson and Ashby (2000) consider broadly similar assemblages to be vulnerable within the state. Based on published floristic analyses this community type does not appear to be represented in other reserves and no synonymous assemblages are described. Hence, it is likely that this grouping of taxa is rather unique to the area with broad structural and some floristic similarities with communities described for Boonoo Boonoo NP (Hunter 1999) and Warra NP (Hunter 2001).

Community 4: *Leptospermum trinervium* (Tea-tree) – *Kunzea obovata* (Pink Kunzea) – *Leptospermum novae-angliae* (New England Tea-tree) Heath and Shrubland

Environmental relationships: restricted to exposed granitic outcrops. Soils are well drained skeletal and of coarse sand.

Structure: heath and shrubland. Tree layer: 10–15 m tall; 10% cover if present, usually absent. Tall shrub layer: 6–12 m tall; 5–10% cover, sometimes absent. Low shrub layer: 1–5 m tall; 10–20% cover, sometimes absent. Understorey layer: < 1 m tall; 20% cover.

Trees: *Allocasuarina littoralis, Eucalyptus oreades, Eucalyptus williamsiana, Eucalyptus olida, Eucalyptus campanulata, Lophostemon confertus.*

Community 4 *Leptospermum trinervium* and *Kunzea obovata* Heath and Shrubland.

Shrubs: *Leptospermum trinervium, Hibbertia linearis, Kunzea obovata, Monotoca scoparia, Phebalium squamulosum, Leucopogon melaleucoides, Acrotriche aggregata, Acacia obtusifolia Leptospermum novae-angliae, Hovea pedunculata, Homoranthus lunatus, Callistemon sieberi, Zieria smithii, Mirbelia pungens, Leucopogon neoanglicus, Leucopogon lanceolatus, Leucopogon hookeri, Elaeocarpus reticulatus, Calytrix tetragona, Callitris oblonga, Amperea xiphoclada, Acacia ulicifolia Pultenaea myrtoides, Pomaderris lanigera, Pomaderris eriocephala, Podolobium ilicifolium, Pimelea bracteata, Petrophile canescens, Persoonia oleoides, Mirbelia rubiifolia, Jacksonia scoparia, Hibbertia serpyllifolia, Dodonaea rhombifolia, Comesperma sylvestre, Callistemon pallidus, Aotus subglauca.*

Climbers & trailers: *Davallia solida.*

Ground cover: *Lomandra longifolia, Laxmannia compacta, Lepidosperma gunnii, Entolasia stricta, Actinotus helianthi, Stylidium graminifolium, Schoenus melanostachys, Pomax umbellata, Patersonia glabrata, Gonocarpus tetragynus, Trachymene incisa, Stylidium laricifolium, Austrodanthonia monticola, Themeda australis, Thelionema grande, Lomandra confertifolia, Velleia spathulata, Pteridium esculentum, Platysace lanceolata, Patersonia sericea, Lomandra filiformis, Isotoma anethifolia, Haemodorum planifolium, Gleichenia dicarpa, Gahnia sieberiana, Dianella revoluta, Dianella caerulea, Cheilanthes sieberi, Brachyscome nova-anglica, Austrostipa scabra, Austrodanthonia racemosa.*

Introduced taxa: none apparent.

Variability: highly variable in structure. Overall, outcrop communities are highly structured by stochastic distributions and frequent sporadic colonisation and extinction and hence they can appear structurally very dissimilar even when in close proximity to each other. The occasional tree can be present giving a low open woodland appearance. Shrubs can be prominent and dense in some localities, giving a dense tall heath appearance. However, overall a large number of shared species occur, including many outcrop endemics, that enable delineation of the assemblage based purely on floristics.

Conservation status: Hunter & Clarke (1998) suggested that this Element was inadequately reserved however with the dedication of Basket Swamp NP, Butterleaf NP and Warra NP the community should now be considered adequately reserved within the state reserve system. This does not mean that further inclusions of this assemblage would not be important as Hunter (2000, 2002b, 2003ab, 2004) has shown, the nature of naturally fragmented ecosystems means that any addition to the reserve network would significantly increase species richness and resilience of this assemblage.

Community 5 *Ceratopetalum apetalum* and *Lophostemon confertus* Closed Forest.

Community 5: *Ceratopetalum apetalum* (Coachwood) – *Lophostemon confertus* (Brush Box) – *Synoum glandulosum* (Scentless Rosewood) Closed Forest

Environmental relationships: restricted to open depressions of deeply incised gullies with a southerly aspect, or at least in a protected position. Soils are moist to damp, grey brown to chocolate brown and of loamy coarse sand or clay loam.

Structure: closed forest often with emergents. Tree layer: 35–45 m tall; 10–40% cover. Tall shrub layer: 15–25 m tall; 20–90% cover. Low shrub layer: 10–15 m tall; 80% cover, usually absent. Understorey layer: < 1 m tall; 30% cover. Figure 8.

Trees: *Ceratopetalum apetalum, Lophostemon confertus, Synoum glandulosum, Schizomeria ovata, Elaeocarpus reticulatus, Acmena smithii, Eucalyptus brunnea, Eucalyptus saligna, Rapanea variabilis, Pittosporum multiflorum, Wilkiea huegeliana, Endiandra sieberi, Acacia filicifolia, Quintinia sieberi, Eucalyptus campanulata, Acacia leucoclada.*

Shrubs: *Tasmannia insipida, Notelaea* sp. A, *Cordyline rubra, Senecio amygdalifolius.*

Climbers & trailers: *Cissus antarctica, Morinda jasminoides, Microsorum pustulatum, Cephalaralia cephalobotrys, Pyrrosia rupestris, Pennantia cunninghamii, Pandorea pandorana, Microsorum scandens, Geitonoplesium cymosum, Eustrephus latifolius, Dendrobium kingianum, Davallia solida, Sarcochilus falcatus, Pyrrosia confluens, Kennedia rubicunda, Hibbertia scandens, Glycine tabacina, Dockrillia pugioniformis, Dendrobium tarberi, Clematis glycinoides, Cissus hypoglauca, Cassine australis, Aneilema acuminatum.*

Ground cover: *Lomandra hystrix, Doodia aspera, Dianella caerulea, Pellaea nana, Asplenium australasicum, Sticherus flabellatus, Lastreopsis decomposita, Calochlaena dubia, Blechnum wattsii, Pteris umbrosa, Peperomia tetraphylla, Hymenophyllum cupressiforme, Helichrysum elatum, Elatostema reticulatum, Cyperus tetraphyllus, Cyathea australis, Adiantum hispidulum, Viola hederacea, Viola betonicifolia, Solanum nobile, Sigesbeckia australiensis, Lomandra longifolia, Hypolepis glandulifera, Gahnia sieberiana, Dicksonia antarctica, Acacia leucoclada.*

Introduced taxa: *Axonopus affinis.*

Variability: the understorey is a mosaic of closed forest mesomorphic understorey to dense stands of ferns and grasses along the margins. This community is highly stochastic in terms of composition as which species occur and in what numbers depends on time since fire, its intensity and frequency all of which are different at each locality.

Conservation status: similar assemblages are considered adequately reserved across there range at present. At least 607 ha of vegetation of very similar composition is reserved within Western Washpool NP (Hunter 2000b).

Community 6: *Eucalyptus obliqua* (Messmate Stringybark) – *Eucalyptus campanulata* (Eastern New England Blackbutt) Tall Open Forest

Environmental relationships: found on lower slopes and open depressions. Soils are deep moist, grey black and sandy loam in texture.

Structure: tall open forest. Tree layer: 35–40 m tall; 30% cover. Tall shrub layer: 3–8 m tall; 20% cover. Low shrub layer: 1.5 m tall; 90% cover. Understorey layer: < 1 m tall; 20%.

Trees: *Eucalyptus obliqua, Eucalyptus campanulata.*

Shrubs: *Acacia obtusifolia Pultenaea daphnoides, Lomatia silaifolia, Leucopogon lanceolatus, Elaeocarpus reticulatus, Acacia filicifolia Trimenia moorei, Rapanea variabilis, Olearia convenyi, Notelaea* sp. A, *Maytenus silvestris, Hibbertia villosa, Hakea eriantha, Banksia cunninghamii, Acrotriche aggregata.*

Community 6 *Eucalyptus obliqua* and *Eucalyptus campanulata* Tall Open Forest.

Climbers & trailers: *Cissus antarctica, Smilax australis, Ripogonum discolor, Desmodium varians.*

Ground cover: *Calochlaena dubia, Gonocarpus oreophilus, Doodia aspera, Gahnia sieberiana, Dianella caerulea, Cyathea australis, Sticherus urceolatus, Pteridium esculentum, Patersonia glabrata, Microlaena stipoides, Lomandra filiformis, Lepidosperma laterale, Helichrysum elatum, Dianella revoluta.*

Introduced taxa: none apparent.

Variability: variability within this community is largely based on time since fire. Such assemblages are best developed in the deeper upland gullies and directly below the larger rock outcrops. However large edge to area ratio means that fire can and does regularly incur and change the more mesic understorey to a more sclerophyllous type of assemblage. Tree ferns or soft ground ferns may be dense and prevalent, at times if a hot fire incursion has occurred a dense cohort of legumes may be found or under lowered fire frequencies closed forest taxa commonly occur in the understorey.

Conservation status: this assemblage is well reserved across the escarpment areas of north eastern NSW and is known to occur within the Mt McKenzie NR, Gibraltar Range NP, Capoompeta NP, Western Washpool NP, Washpool NP, Guy Fawkes River NP, Bald Rock NP, Butterleaf NP, Warra NP, Boorolong NR, New England NP and Boonoo Boonoo NP and is threatened by too frequent fire regimes. Despite this the assemblage type is probably at the northern limit of its distribution and is of limited extent within Basket Swamp NP and also limited in Bald Rock and Boonoo Boonoo NPs (Hunter 1999). This community should be considered moderately conserved locally and adequately across the state.

Community 7 *Baeckea omissa* and *Baloskion stenocoleum* Heathy Sedgeland.

Community 7: *Baeckea omissa* (Baeckea) – *Baloskion stenocoleum* (Sedge) Heathy Sedgeland

Environmental relationships: found in open and closed depressions on Quaternary Alluvium. Soils are waterlogged to damp, dark grey to black in colour and of cracking silt and clay, loam or peaty in texture.

Structure: closed heath and sedgeland. Tall shrub layer: 8–12 m tall; 10% cover. Low shrub and sedge layer: < 2 m tall; 80–100% cover.

Trees: *Eucalyptus pauciflora, Eucalyptus notabilis, Eucalyptus dalrympleana, Eucalyptus campanulata, Eucalyptus brunnea.*

Shrubs: *Baeckea omissa, Callistemon pityoides, Epacris microphylla, Banksia cunninghamii, Leptospermum gregarium, Callistemon pallidus, Pultenaea villosa, Pimelea glauca, Leptospermum arachnoides, Hakea microcarpa, Grevillea acanthifolia, Boronia parviflora, Pultenaea pycnocephala, Xanthorrhoea glauca, Leptospermum trinervium, Leptospermum polygalifolium, Hibbertia acicularis, Callistemon sieberi, Petrophile canescens, Isopogon petiolaris, Hibbertia pedunculata, Daviesia nova-anglica, Boronia microphylla.*

Climbers & trailers: none apparent.

Ground cover: *Baloskion stenocoleum, Gymnoschoenus sphaerocephalus, Gleichenia dicarpa, Xyris operculata, Lycopodiella cernua, Lepidosperma limicola, Thelionema grande, Lepyrodia anarthria, Gonocarpus micranthus, Entolasia stricta, Eleocharis sphacelata, Thelionema caespitosum, Schoenus melanostachys, Lindsaea linearis, Geranium solanderi, Gahnia sieberiana, Drosera binata, Deyeuxia imbricata, Craspedia variabilis, Austrostipa rudis, Schoenus apogon, Lepidosperma tortuosum, Goodenia bellidifolia, Utricularia dichotoma, Themeda triandra, Rhynchospora brownii, Nymphoides geminata, Juncus continuus, Isolepis subtilissima, Hypericum japonicum, Goodenia hederacea, Entolasia marginata, Empodisma minus, Deyeuxia appressa, Xyris complanata, Tricoryne elatior, Trachymene incisa, Stylidium graminifolium, Philydrum lanuginosum, Patersonia sericea, Myriophyllum pedunculatum, Lomandra multiflora, Lomandra longifolia, Lepidosperma laterale, Juncus usitatus, Imperata cylindrica, Haemodorum planifolium, Gonocarpus tetragynus, Gonocarpus oreophilus, Fimbristylis dichotoma, Drosera burmannii, Austrodanthonia racemosa.*

Introduced taxa: *Axonopus affinis, Phalaris aquatica, Cyperus eragrostis.*

Variability: this community has a number of species with high constance and many that were poorly associated. This community is isolated, small and generally of limited distribution and as such although a number of species will almost always be present and dominant many other associated taxa are likely to be highly variable in occurrence. The community as defined here may be separated into grass and cyperiod dominated areas along with situations with a strong shrub component. This internal variability within individual occurrences is primarily due to depth and duration of water logging. Zones can often be distinguished that are banded based on proximity to creek channels. In a few localities *Sphagnum* bogs have developed. In some small creek lines drainage can be impeded and this community may develop and be only a few meters wide, in such instances sedges appear to be more prominent.

Conservation status: communities such as these are usually highly divergent across relatively small distances and as such most occurrences are somewhat unique. Benson and Ashby (2000) considered this type of assemblage to be poorly conserved locally but moderately conserved within the state. Similar small isolated occurrences are likely to be within most reserves on the escarpment and associated tablelands areas from the Queensland border to Barrington and Coolah Tops. Broadly, similar assemblages are known to be reserved within Gibraltar Range NP, New England NP, Warra NP, Boonoo Boonoo NP, Bald Rock NP, Girraween NP, Demon NR, Cathedral Rocks NP, Coolah Tops NP, Western Washpool NP, Capoompeta NP and Butterleaf NP. Despite the above, areas which include *Sphagnum*, should be considered critically endangered on the tablelands as only a few instances in good condition survive and it is likely that only a few hectares of these bogs occur across the whole tablelands.

Discussion

Phytogeography

Community 1 is similar to assemblages described as occurring just of the Queensland border and then as far south as Guyra (Backwater). It is in general restricted to higher altitudes above 1000 m on coarse acid soils. The drier grassy variant on Community 2 commonly occurs up to 1100 m. Binns (1995a) describes a very synonymous community in Maryland State Forest where it extensive on granite in low relief drainage lines and lower slopes. Divergent but a somewhat floristically similar community is described by Elsol (1991) as occurring as far north as Toowoomba. In the surveys of State Forests conducted in the north east of NSW (King 1985, Binns 1991, Binns 1992, Moore & Floyd 1994, Binns 1995a, Binns 1995b, Chapman & Binns 1995) similar assemblages have been described as occurring from the Kempsey and Wauchope areas north to Tenterfield and Urbenville.

In contrast, Communities 3 and 4 have more restricted distributions at high altitudes from Tenterfield south the Walcha area. Both are associated with granitic landscapes with outcropping and subsurface granite. Community 3 shares a number of species with Community 4 but both also have a number of very distinctive species due to the predominance of particular habitat specialists. The floristics of Community 3 is dynamic due to a constant cycle of regular disturbance by flooding and fire. Community 4 is incorporated within Element 1 of Hunter & Clarke (1998) which occurs along the eastern escarpment from Girraween and Bald Rock National Parks as far south as Cathedra Rock National Park. Unlike Community 3, it is not prone to regular flooding and less likely affected by fire (Hunter, 1998, Hunter et al. 1998, Hunter 2003a).

Placement of Community 5 within other described assemblages is difficult as it appears to be a derived rather than natural assemblage due to high frequency fires and the very linear and remnant nature of stands. This is further complicated by the sites being marginal for *Lophostemon confertus* due to low soil fertility and high altitude (Binns 1995b). As stands mature they are likely to be similar to Floyds sub-alliance 35: *Ceratopetalum/Schizomeria – Caldcluvia* (Floyd 1990). Such assemblages are considered to be common, from south of Tenterfield along the escarpment at higher altitudes, particularly in the Washpool area where extensive stands are reserved in Washpool National Park. It is likely that under lowered fire regimes expansion of this assemblage will occur and succession to Floyds sub-alliance 35 may be an outcome.

Community 6 is closely similar to the *Eucalyptus campanulata* Alliance as described by Beadle (1981), occurring at higher altitudes from just over the Queensland border to Barrington Tops. McDonald and Whiteman (1979) describe an *E. campanulata* community that varies from a tall forest with a partial closed forest understorey to a shorter forest with a shrubbier understorey. McDonald and Whiteman (1979) map a disjunct occurrence of this community in small areas from Canangra Creek near the Darlington Range to Tallebundgera Mountain near Lamington. Flora surveys conducted by the State Forests of New South Wales in their management areas (Binns & Chapman 1993, Binns 1995a, c) describe similar assemblages. These are found from the Tenterfield region south to the Carrai Plateau and to Barrington Tops. All described occurrences are at altitudes above 900 m. Binns (1995a) considered this association as possibly the most widespread community in the Tenterfield area above 900 m on all geological substrates.

Broadly similar assemblages to Community 7 are described as occurring at higher altitudes along the eastern escarpment from Girraween NP in Queensland to as far south as the Walcha area (Hunter 2004). However, more closely allied assemblages are probably restricted to the general area such as from Bald Rock to the Malara Plateau (Hunter 1999, Hunter et al. 1999).

Few comparable assemblages are described that are similar to Community 7. Similar assemblages are restricted to higher altitudes on the tablelands particularly along the eastern margin of the divide.

Species richness

Four hundred and thirty taxa were found within Basket Swamp National Park, which is similar to many other comparably sized reserves within the bioregion such as Single National Park (424, Clarke et al. 2000), Bluff River Nature Reserve (367, Hunter 2002a), Warra National Park (495, Hunter 2001). Species density (richness per site) (31 spp. per 0.1 ha) was lower than other reserves in the local region such as Bald Rock and Boonoo Boonoo National parks (50, Hunter 1999), Demon Nature Reserve (51, Hunter et al. 1999), Capoompeta and Western Washpool National Parks (42, Hunter 2000b), Bolivia Hill and Bluff River Nature Reserves (41, Hunter 2002a) and Gibraltar Range National Park (36, Sheringham & Hunter 2002). The reasons for this significant decline in species density within Basket Swamp NP compared to neighbouring reserves need further detailed investigation. It is possible that poor rainfall may have contributed or that past land practices such as logging have had a lingering effect. Species density is a complex issue and is often related to many unmeasured characteristics such as species pool sizes for each community type or regional energy inputs (Hunter 2005). Species density is only one aspect of biodiversity and as shown the capture of species within the park (gamma-diversity) was similar to other comparatively sized reserves within the local region, thus indicating a higher beta-diversity.

Conservation issues

Approximately 60% of the woody vegetation in the New England Bioregion has been cleared (Benson 1999). Most of the assemblages within the Park are considered adequately reserved and of little concern currently. The status of these assemblages in recent years has markedly improved in terms of reservation status. Two assemblages though were considered inadequately reserved at this stage and potentially under threat. Community 3 is of limited extent across the tablelands and under pressure for recreation and is prone to weed invasion. This assemblage is poorly conserved within the Park with many areas occurring outside of the boundaries or shared between the reserve and neighbouring landholdings. Community 7 is moderately conserved across the region in terms of area; however swampy areas with sphagnum are of very limited extent. Sphagnum areas are also under threat from climate change. Community 7 has extensive areas with underlying sphagnum and such areas should be considered as endangered.

Thirty-six species were considered of conservation significance within the Park. Two of these are currently listed on the NSW *TSC Act* as Vulnerable and nine have been reported under the RoTAP criteria (Briggs & Leigh 1996). These include: *Callitris oblonga* subsp. *parva* (*TSC* Vulnerable), *Homoranthus lunatus* (*TSC* Vulnerable), *Eucalyptus olida* (2RCa), *Grevillea acanthifolia* subsp. *stenomera* (3RC-), *Daviesia elliptica* (3RC-), *Dodonaea rhombifolia* (3RCa), *Pultenaea pycnocephala* (3RCa), *Thelionema grande* (3RC-), and *Hibbertia villosa* (3KC-). Thirty species were thought to be at or near their geographic limits or were considered as significant due to being locally/regionally rare or highly disjunct in their distribution according to Sheringham & Westaway (1998). These taxa are: *Austrodanthonia monticola, Boronia algida, Coprosma quadrifida, Daviesia nova-anglica, Dillwynia sieberi, Eucalyptus acaciiformis, Eucalyptus notabilis, Euchiton gymnocephalus, Goodenia bellidifolia* subsp. *bellidifolia, Gymnoschoenus sphaerocephalus, Helichrysum rutidolepis, Isotoma anethifolia, Joycea pallida, Juncus sandwithii, Lepyrodia leptocaulis, Leucopogon hookeri, Lomandra filiformis, Myriophyllum pedunculatum, Olearia cowenyi, Oreomyrrhis eriopoda, Patersonia fragilis* and *Acacia viscidula.*

Conclusion

Though many assemblages within Basket Swamp National Park are currently well reserved, both locally and regionally, the Park is important as adjunct to the other local National Parks such as Bald Rock and Boonoo Boonoo. Together these reserves incorporate extensive areas of important little disturbed forests and woodlands of higher altitudes once very common along the eastern escarpment of the Northern Tablelands. The more widespread assemblages within Basket Swamp NP are near their northernmost limits. Communities 3 and 7 are however of limited distribution and the Park is an important area for their conservation.

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Appendix: Flora of Basket Swamp National Park

Taxa found within the survey sites are scored according to their occurrence in each of the seven communities defined. Some taxa were found in previous surveys or opportunistically (+) and therefore are not assigned to a specific community.

1 = Blackbutt – Stringybark Shrubby Open Forests & Woodlands,
2 = Blackbutt – Stringybark Grassy Open Forests,
3 = Tea-tree Riparian Scrubs,
4 = Tea-tree Rock Outcrop Heaths & Shrublands,
5 = Coachwood – Brushbox – Rosewood Closed Forests,
6 = Messmate – Blackbutt Tall Open Forests,
7 = Heathy Sedgelands.

PTERIDOTYPES & ALLIES

Adiantaceae	
Adiantum aethiopicum	+
Adiantum hispidulum	5
Cheilanthes sieberi	2, 4
Pellaea falcata	+
Pellaea nana	5
Aspleniaceae	
Asplenium australasicum	5
Asplenium flabellifolium	2
Blechnaceae	
Blechnum cartilagineum	+
Blechnum minus	+
Blechnum nudum	+
Blechnum wattsii	5
Doodia aspera	1, 2, 5, 6
Cyatheaceae	
Cyathea australis	2, 5, 6
Davalliaceae	
Davallia solida var. *pyxidata*	1, 4, 5
Dennstaedtiaceae	
Calochlaena dubia	2, 5, 6
Hypolepis glandulifera	5
Pteridium esculentum	1, 2, 3, 4, 6
Dicksoniaceae	
Dicksonia antarctica	5
Dryopteridaceae	
Lastreopsis decomposita	5
Gleicheniaceae	
Gleichenia dicarpa	2, 3, 5, 7
Sticherus flabellatus	5
Sticherus urceolatus	6
Hymenophyllaceae	
Hymenophyllum cupressiforme	5
Lindsaeaceae	
Lindsaea linearis	2, 7
Lycopodiaceae	
Lycopodiella cernua	2, 7
Polypodiaceae	
Dictymia brownii	+
Microsorum pustulatum subsp. *pustulatum*	5
Microsorum scandens	5
Platycerium bifurcatum subsp. *bifurcatum*	2, 5
Pyrrosia confluens var. *dielsii*	5
Pyrrosia rupestris	5

Pteridaceae	
Pteris umbrosa	5
CONIFERS	
Cupressaceae	
Callitris oblonga subsp. *parva*	4
MONOCOTYLEDONS	
Anthericaceae	
Arthropodium milleflorum	2
Dichopogon fimbriatus	+
Laxmannia compacta	4
Thysanotus tuberosus	1, 2, 3
Tricoryne elatior	1, 2, 3, 7
Asteliaceae	
Cordyline rubra	5
Centrolepidaceae	
Centrolepis fascicularis	3
Commelinaceae	
Aneilema acuminatum	5
Commelina cyanea	+
Cyperaceae	
Bulbostylis densa	+
Carex breviculmis	+
Carex inversa	+
**Cyperus eragrostis*	7
Cyperus gracilis	+
Cyperus laevis	+
Cyperus tetraphyllus	5
Eleocharis sphacelata	7
Fimbristylis dichotoma	7
Gahnia aspera	2
Gahnia sieberiana	2, 4, 5, 6, 7
Gymnoschoenus sphaerocephalus	7
Isolepis subtilissima	7
Lepidosperma gunnii	4
Lepidosperma laterale	1, 2, 6, 7
Lepidosperma limicola	3, 7
Lepidosperma tortuosum	1, 7
Rhynchospora brownii	3, 7
Schoenus apogon	1, 3, 7
Schoenus melanostachys	1, 2, 3, 4, 7
Eriocaulaceae	
Eriocaulon scariosum	+
Haemodoraceae	
Haemodorum planifolium	1, 4, 7
Hypoxidaceae	
Hypoxis hygrometrica	+
Iridaceae	
Patersonia fragilis	+
Patersonia glabrata	1, 2, 3, 4, 6
Patersonia sericea	1, 2, 3, 4, 7
Juncaceae	
**Juncus bufonius*	3
Juncus continuus	7
Juncus pauciflorus	1, 2
Juncus sandwithii	3
Juncus usitatus	7
Luzula flaccida	+
Juncaginaceae	
Triglochin multifructum	3
Lomandraceae	
Lomandra confertiflora subsp. *pallida*	2, 3, 4
Lomandra filiformis subsp. *coriacea*	1, 2, 4, 6
Lomandra hystrix	5
Lomandra longifolia	1, 2, 3, 4, 5, 7
Lomandra multiflora	1, 2, 3, 7
Luzuriagaceae	
Eustrephus latifolius	1, 2, 5
Geitonoplesium cymosum	2, 5
Orchidaceae	
Dendrobium kingianum	5
Dendrobium tarberi	5
Dipodium variegatum	2
Dockrillia pugioniformis	1, 5
Microtis unifolia	+
Sarcochilus falcatus	5
Phormiaceae	
Dianella caerulea var. *assera*	1, 2, 4, 5, 6
Dianella var. *caerulea*	1, 2
Dianella revoluta	1, 2, 3, 4, 6
Stypandra glauca	+
Thelionema caespitosa	7
Thelionema grande	4, 7
Poaceae	
Austrodanthonia eriantha	3
Austrodanthonia monticola	4
Austrodanthonia racemosa var. *racemosa*	1, 2, 4, 7
Austrodanthonia tenuior	2
Austrostipa rudis subsp. *rudis*	1, 2, 3, 7
Austrostipa scabra	1, 2, 4
**Axonopus affinis*	2, 5, 7
Cymbopogon refractus	+
Deyeuxia imbricata	7
Deyeuxia parviseta var. *parviseta*	1, 2
Dichelachne micrantha	1, 2
Dichelachne sieberiana	1
Digitaria parviflora	+
Digitaria ramularis	2, 3
Echinopogon caespitosus var. *caespitosus*	1, 2
Echinopogon ovatus	+
Entolasia marginata	1, 2, 7
Entolasia stricta	1, 2, 4, 7
Eragrostis elongata	+
Imperata cylindrica var. *major*	1, 2, 7
Joycea pallida	1, 2
Microlaena stipoides var. *stipoides*	1, 2, 6
Notodanthonia longifolia	4
Oplismenus imbecillus	2
Panicum simile	1, 3
Paspalum distichum	1
**Phalaris aquatica*	7
Poa queenslandica	2
Poa sieberiana var. *sieberiana*	1, 2, 3
Sorghum leiocladum	1, 2
Sporobolus creber	+
Themeda australis	1, 2, 3, 4, 7
Tripogon loliiformis	+
Restionaceae	
Baloskion stenocoleum	2, 7
Empodisma minus	7
Lepyrodia anarthria	3, 7
Lepyrodia leptocaulis	+
Ripogonaceae	
Ripogonum discolor	6
Smilacaceae	
Smilax australis	1, 2, 6
Xanthorrhoeaceae	
Xanthorrhoea glauca subsp. *glauca*	1, 2, 3, 7
Xanthorrhoea johnsonii	

Xyridaceae	
Xyris complanata	7
Xyris operculata	3, 7
DICOTYLEDONS	
Acanthaceae	
Brunoniella australis	+
Apiaceae	
Actinotus helianthi	3, 4
Daucus glochidiatus	+
Hydrocotyle laxiflora	+
Hydrocotyle peduncularis	2
Hydrocotyle tripartita	+
Oreomyrrhis eriopoda	+
Platysace ericoides	1
Platysace lanceolata	1, 2, 4
Trachymene incisa	
Apocynaceae	
Parsonsia straminea	+
Araliaceae	
Cephalaralia cephalobotrys	5
Polyscias sambucifolia	1, 2
Asclepiadaceae	
**Gomphocarpus fruticosus*	+
Asteraceae	
Brachyscome microcarpa	+
Brachyscome nova-anglica	1, 2, 3
Brachyscome stuartii	3
**Bidens subalternans*	2
Chrysocephalum apiculatum	2
Chrysocephalum semipapposum	+
**Cirsium vulgare*	+
**Conyza albida*	2
**Conyza bonariensis*	+
Craspedia variabilis	7
Euchiton gymnocephalus	+
Euchiton involucratus	+
Euchiton sphaericus	1, 2
Helichrysum elatum	1, 2, 5, 6
Helichrysum rutidolepis	2
Helichrysum scorpioides	2
**Hypochaeris glabra*	1
**Hypochaeris radicata*	1, 2, 3
Lagenifera stipitata	+
Olearia covenyi	6
Ozothamnus diosmifolius	+
**Picris hieracioides*	2
Podolepis jaceoides	1, 2
Podolepis neglecta	+
Pseuderanthemum variabile	+
Senecio amygdalifolius	5
Senecio diaschides	1, 2
Sigesbeckia australiensis	5
Solenogyne bellioides	+
Solenogyne dominii	+
**Taraxacum officinale*	+
Vernonia cinerea var. *cinerea*	1,2
Xerochrysum bracteatum	+
Baueraceae	
Bauera rubioides var. *rubioides*	3
Bignoniaceae	
Pandorea pandorana	2, 5
Campanulaceae	
Wahlenbergia communis	2
Wahlenbergia gracilis	+
Wahlenbergia graniticola	1
Wahlenbergia luteola	+
Wahlenbergia planiflora subsp. *longipila*	3
Wahlenbergia stricta subsp. *stricta*	+
Caryophyllaceae	
**Petrorhagia nanteuilii*	+
Scleranthus biflorus	+
Casuarinaceae	
Allocasuarina littoralis	1, 2, 3, 4
Allocasuarina torulosa	2, 3
Celastraceae	
Cassine australis var. *australis*	5
Maytenus bilocularis	2
Maytenus silvestris	1, 2, 6
Chenopodiaceae	
Chenopodium pumilio	+
Clusiaceae	
Hypericum gramineum	2, 3
Hypericum japonicum	3, 7
Convolvulaceae	
Dichondra repens	+
Crassulaceae	
Crassula sieberiana	2
Cunoniaceae	
Ceratopetalum apetalum	5
Schizomeria ovata	5
Dilleniaceae	
Hibbertia acicularis	3, 7
Hibbertia aspera subsp. *pilosifolia*	1
Hibbertia dentata	2
Hibbertia linearis	1, 4
Hibbertia obtusifolia	1, 2
Hibbertia pedunculata	7
Hibbertia scandens	2, 5
Hibbertia serpyllifolia	1, 4
Hibbertia villosa	1, 2, 3, 6
Droseraceae	
Drosera binata	7
Drosera burmannii	7
Drosera spatulata	3
Elaeocarpaceae	
Elaeocarpus reticulatus	1, 2, 4, 5, 6
Epacridaceae	
Acrotriche aggregata	1, 2, 3, 4, 6
Brachyloma daphnoides subsp. *glabrum*	+
Epacris microphylla var. *microphylla*	1,2, 7
Epacris obtusifolia	3
Leucopogon hookeri	+
Leucopogon lanceolatus var. *lanceolatus*	1, 2, 4, 6
Leucopogon melaleucoides	4
Leucopogon neoanglicus	3, 4
Lissanthe strigosa	+
Melichrus procumbens	1
Melichrus urceolatus	1, 2
Monotoca scoparia	1, 2, 4
Trochocarpa laurina	2, 5
Escalloniaceae	
Quintinia sieberi	5
Euphorbiaceae	
Amperea xiphoclada var. *xiphoclada*	1, 2, 4
Breynia cernua	+
Phyllanthus hirtellus	1
Phyllanthus virgatus	1
Poranthera microphylla	1, 2
Eupomatiaceae	
Eupomatia laurina	5

Fabaceae	
Acacia falciformis	1, 2
Acacia filicifolia	2, 3, 5, 6
Acacia fimbriata	2, 3
Acacia floribund	1, 2, 3
Acacia implexa	2
Acacia leiocalyx subsp. *leiocalyx*	1
Acacia leucoclada subsp. *leucoclada*	2, 5
Acacia melanoxylon	2
Acacia myrtifolia	1, 2
Acacia obtusifolia	1, 2, 4, 6
Acacia rubida	+
Acacia ulicifolia	1, 3, 4
Acacia venulosa	3, 4
Acacia viscidula	5
Aotus subglauca var. *subglauca*	4, 7
Bossiaea neoanglica	1, 2, 3
Bossiaea scortichinii	2
Daviesia elliptica	1, 2
Daviesia nova-anglica	1, 7
Desmodium rhytidophyllum	1, 2
Desmodium varians	1, 2, 6
Dillwynia phylicoides	1, 2
Dillwynia sieberi	3
Glycine clandestina	1, 2
Glycine tabacina	1, 2
Gompholobium latifolium	1
Hardenbergia violacea	1, 2
Hovea heterophylla	2
Hovea pedunculata	3, 4
Indigofera australis	2
Jacksonia scoparia	1, 4
Kennedia rubicunda	2, 5
Mirbelia pungens	4
Mirbelia rubiifolia	4
Podolobium ilicifolium	1, 2, 4
Pultenaea daphnoides	1, 6
Pultenaea myrtoides	2, 4
Pultenaea pycnocephala	7
Pultenaea sp. G	1
Pultenaea villosa	1, 2, 3, 7
Swainsona galegifolia	+
Gentianaceae	
**Centaurium erythraea*	+
Geraniaceae	
Geranium solanderi var. *grande*	7
Geranium solanderi var. *solanderi*	1, 2
Goodeniaceae	
Dampiera stricta	1
Goodenia bellidifolia subsp. *bellidifolia*	1, 2, 7
Goodenia hederacea subsp. *hederacea*	1, 2, 3, 7
Velleia spathulata	4
Haloragaceae	
Gonocarpus micranthus subsp. *ramosissimus*	3, 7
Gonocarpus oreophilus	1, 2, 3, 6, 7
Gonocarpus tetragynus	1, 2, 4, 7
Gonocarpus teucrioides	1, 2
Haloragis heterophylla	+
Myriophyllum pedunculatum subsp. *pedunculatum*	7
Icacinaceae	
Pennantia cunninghamii	5
Lamiaceae	
Ajuga australis	2
Mentha satureioides	+
Plectranthus graveolens	+
Prostanthera sp. *B*	1, 3

Lauraceae	
Cassytha pubescens	1, 2, 3
Endiandra sieberi	5
Lentibulariaceae	
Utricularia dichotoma	3, 7
Lobeliaceae	
Isotoma anethifolia	+
Lobelia gibbosa	1, 2
Pratia purpurascens	1, 2
Loranthaceae	
Amyema miquelii	1, 4
Amyema pendula	+
Meliaceae	
Synoum glandulosum	5
Menyanthaceae	
Nymphoides geminata	7
Monimiaceae	
Hedycarya angustifolia	5
Wilkiea huegeliana	2, 5
Menispermaceae	
Sarcopetalum harveyanum	5
Myrsinaceae	
Rapanea howittiana	5
Rapanea variabilis	5, 6
Myrtaceae	
Acmena smithii	5
Angophora subvelutina	2
Baeckea omissa	3, 7
Callistemon pallidus	3, 4, 7
Callistemon pityoides	7
Callistemon sieberi	4, 7
Calytrix tetragona	3, 4
Eucalyptus acaciiformis	1
Eucalyptus brunnea	1, 2, 3, 5, 7
Eucalyptus caliginosa	2
Eucalyptus cameronii	1, 2
Eucalyptus campanulata	1, 2, 3, 4, 5, 6, 7
Eucalyptus dalrympleana subsp. *heptantha*	7
Eucalyptus laevopinea	1
Eucalyptus notabilis	1, 2, 7
Eucalyptus obliqua	2, 6
Eucalyptus olida	4
Eucalyptus oreades	4
Eucalyptus pauciflora	7
Eucalyptus radiata subsp. *sejuncta*	1
Eucalyptus saligna	2, 5
Eucalyptus williamsiana	1, 4
Homoranthus lunatus	4
Kunzea obovata	4
Leptospermum arachnoides	7
Leptospermum gregarium	7
Leptospermum minutifolium	1, 2
Leptospermum nova-angliae	4
Leptospermum polygalifolium subsp. *transmontanum*	1, 3, 7
Leptospermum trinervium	1, 2, 3, 4, 7
Lophostemon confertus	1, 4, 5
Oleaceae	
Notelaea longifolia	+
Notelaea ovata	1, 2
Notelaea sp. *A*	1, 5, 6
Notelaea venosa	+
Onagraceae	
Epilobium billardierianum subsp. *cinereum*	+
Oxalidaceae	
Oxalis chnoodes	+
Oxalis perennans	+

Peperomiaceae	
Peperomia tetraphylla	5
Philydraceae	
Philydrum lanuginosum	7
Pittosporaceae	
Billardiera scandens	1, 2
Pittosporum multiflorum	5
Pittosporum undulatum	+
Rhytidosporum diosmoides	1
Plantaginaceae	
Plantago debilis	+
Plantago varia	+
Polygalaceae	
Comesperma sylvestre	1, 4
Persicaria decipiens	+
Polygala japonica	1, 2
Polygonaceae	
Rumex brownii	+
Primulaceae	
**Anagallis arvensis*	+
Proteaceae	
Banksia cunninghamii	1, 2, 3, 6, 7
Banksia integrifolia	1, 2, 3
Grevillea acanthifolia subsp. *stenomera*	7
Hakea eriantha	1, 2, 6
Hakea florulenta	1, 2
Hakea laevipes subsp. *graniticola*	1
Hakea microcarpa	7
Isopogon petiolaris	1, 7
Lomatia silaifolia	1, 2, 3, 6
Persoonia cornifolia	1
Persoonia oleoides	1, 3
Persoonia sericea	1, 2, 3, 4
Persoonia tenuifolia	+
Petrophile canescens	1, 3, 4, 7
Ranunculaceae	
Clematis aristata	+
Clematis glycinoides	5
Ranunculus lappaceus	1, 2
Rhamnaceae	
Pomaderris argyrophylla subsp. *graniticola*	3
Pomaderris eriocephala	4
Pomaderris lanigera	3, 4
Rosaceae	
Acaena novae-zelandiae	+
Rubus parvifolius	2
Rubiaceae	
Asperula conferta	+
Coprosma quadrifida	3
Galium migrans	2
Morinda jasminoides	1, 2, 5
Opercularia aspera	1
Opercularia diphylla	1, 2
Pomax umbellata	1, 2, 4
Psychotria loniceroides	5
Rutaceae	
Boronia algida	1
Boronia microphylla	1, 7
Boronia parviflora	7
Correa reflexa var. *reflexa*	3
Phebalium squamulosum subsp. *squamulosum*	4
Zieria fraseri subsp. *compacta*	
Zieria smithii subsp. *smithii*	1, 4
Santalaceae	
Choretrum candollei	+
Exocarpus cupressiformis	1, 3
Sapindaceae	
Dodonaea rhombifolia	4
Dodonaea viscosa var. *angustifolia*	+
Scrophulariaceae	
Veronica calycina	1
Veronica plebeia	+
Solanaceae	
Solanum campanulatum	1, 2
Solanum nobile	5
Solanum prinophyllum	1
Stackhousiaceae	
Stackhousia viminea	+
Stylidiaceae	
Stylidium graminifolium	1, 2, 4, 7
Stylidium laricifolium	1, 4
Thymelaeaceae	
Pimelea bracteata	4
Pimelea glauca	7
Pimelea linifolia subsp. *collina*	1, 3
Tremandraceae	
Tetratheca thymifolia	1
Trimeniaceae	
Trimenia moorei	6
Urticaceae	
Elatostema reticulatum var. *reticulatum*	5
Violaceae	
Hybanthus monopetalus	1, 2
Hybanthus stellarioides	+
Viola betonicifolia	1, 2, 5
Viola hederacea	1, 5
Vitaceae	
Cissus antarctica	5, 6
Cissus hypoglauca	5
Winteraceae	
Tasmannia insipida	1, 2, 3

Using environmental variables and multivariate analysis to delineate preferred habitat for *Cryptostylis hunteriana*, the Leafless Tongue Orchid, in the Shoalhaven Local Government Area, NSW

Stephen Clark, Claire deLacey and Steven Chamberlain

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Abstract: An improved approach to predicting preferred habitat and targetting survey effort for threatened plant species is needed to aid discovery and conservation of new populations. This study employs several approaches to aid in the delineation of preferred habitat for the Leafless Tongue Orchid, *Cryptostylis hunteriana* Nicholls. BIOCLIM, a bioclimatic analysis and prediction system, is used initially to generate a bioclimatic habitat envelope within which the species can be expected to occur, based on all known sites in the Shoalhaven Local Government Area. Within the BIOCLIM envelope it is possible to further investigate the extent to which the species exhibits preferences for other habitat factors such as geology, soil landscapes and forest ecosystems. Multivariate techniques are used to compare floristic data from sites where *Cryptostylis hunteriana* is present, and sites from forest ecosystems where it has not been recorded historically. These techniques are also used to identify species which are diagnostic of each of these sets of sites. All 25 sites with *Cryptostylis hunteriana* populations are restricted to six forest ecosystems having a total area of 15% of the Shoalhaven Local Government Area and 47% of the BIOCLIM envelope. Within these forest ecosystems, ten plant species deemed indicative of the possible presence of the *Cryptostylis hunteriana* are identified.

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Introduction

Cryptostylis hunteriana Nicholls (family Orchidaceae), the Leafless Tongue Orchid (Fig. 1), is a rare, leafless saprophytic terrestrial orchid listed as Vulnerable on Schedule 2, of the NSW *Threatened Species Conservation Act, 1995* (TSC Act). It is also listed as Vulnerable under the provisions of the *Environment Protection and Biodiversity Conservation Act* 1999 (Commonwealth) (EPBC Act) and has a RoTAP coding (Briggs & Leigh 1996) of (3VC-), indicating that the species is vulnerable, and has a geographic range greater than 100km, with at least one population (population size unknown) occurring in a conservation reserve.

There is an increasing need to improve our understanding of preferred habitat for rare plant species, particularly for those species regarded as cryptic. *Cryptostylis hunteriana* can be particularly hard to detect beyond its short-lived flowering event, as a consequence of its limited flowering period and the lack of above-ground parts. It is often the case for geophytic orchid species that little is known of their distribution and habitat preferences at the time of their listing on schedules of State and Commonwealth legislation, with the consequence that effective recovery planning may either be delayed or be ineffectual.

Lack of knowledge of preferred habitat can also place species at risk in areas undergoing rapid and intensive development. Section 79C(1)(b) of the NSW *Environmental Planning and Assessment Act* 1979 (EP&A Act) requires consideration of '*...the likely impacts of that development,*

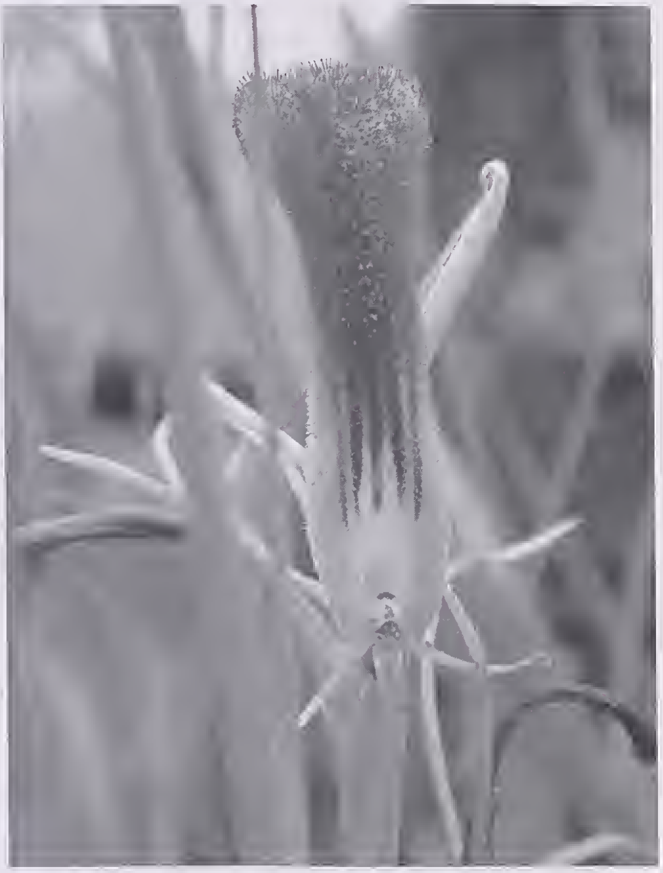


Fig. 1. Leafless Tongue Orchid, *Cryptostylis hunteriana*, at Callala, Jervis Bay (Photo: Claire deLacey).

including environmental impacts on both the natural and built environments...'. Particularly relevant in this regard is the '8-part test' under s5A of the EP&A Act in relation to threatened species, whose points are designed to determine '...*whether there is likely to be a significant effect on threatened species, populations or ecological communities, or their habitats*...'. A better understanding of what constitutes preferred habitat for such species can improve our ability to meet conservation objectives for threatened species and their habitats. Any refinement in the delineation of habitat preferences for threatened species can also save time and resources, as it makes it possible to concentrate survey effort in those areas where the species is more likely to occur.

Cryptostylis hunteriana has been selected for this investigation on the basis that its distribution is incompletely known at present, and it is a species under threat from development, both within the Shoalhaven City Council area and in other parts of its known range. The species is amenable to study, as a sufficient number of sites have been identified (at least within the Shoalhaven region) to make an analysis of habitat preferences possible.

Our objective is to investigate the extent to which an existing dataset can be used to refine our understanding of habitat preferences for a threatened species with a limited number of known occurrences. It is often a characteristic of rare (and particularly cryptic) plant species that to find additional populations, expensive and time consuming field work is required, but that formal survey approaches, such as stratified random sampling (Austin & Heyligers, 1989), have very limited application. It is also the case that some of the modelling approaches, such as Generalized Linear Models (GLMs) and Generalized Additive Models (GAMs), that have been developed in recent years (Yee & Mitchell, 1991) require more data than are typically available for such species. For example, Elith (2003) using GLMs and GAMs found that the rarity of *Westringia davidii* placed severe restrictions on the number of variables that could be used, and that the explanatory power of the model developed in that study was limited.

The approach taken in this paper belongs to the category of environmental envelopes discussed by Guisan and Zimmermann (2000). In this approach, an initial envelope is divided into sub-envelopes with varying probabilities of occurrence of the species under consideration within each sub-envelope. In this study, BIOCLIM is used to identify the initial environmental envelope which constitutes the study area. Within this study area, we have made use of indirect parameters (geology, soil landscapes and vegetation), since we are interested primarily in the prediction of preferred habitat, rather than attempting to identify specific physiologically relevant factors. As Guisan and Zimmermann (2000) observe, there is often good correlation between such variables and observed species patterns. This is because they serve to integrate several different kinds of ecologically relevant information.

The ecological literature recognises that there is what may be termed a hierarchy of environmental influences, which relates broadly to scale (Mackey & Lindenmayer 2001, Davey & Stockwell 1991) on the distribution of many plant species. At a regional scale, differences in climate influence both the occurrence (presence/absence) and population parameters (abundance) of a given species. At a more local scale, differences in geology, soils and vegetation (each in turn dependent to some degree on the other) are also known to exert a significant influence. In considering geology, soil landscapes and vegetation, two alternative approaches were available:

(i) investigation of each of the three parameters independently in order to assess their comparative value in determining preferred habitat and;

(ii) adoption of a tiered or nested system in which the habitat identified by each variable formed a sub-envelope in which the next variable was assessed.

In this paper, the former approach is taken, recognising Mackey and Lindenmeyer's (2001) assertion that while each variable constrains the next (e.g. lithology constrains soil landscape), it does not necessarily wholly contain it. Given our present limited understanding of how various factors interact to influence the distribution of *Cryptostylis hunteriana*, it was considered advisable to take the more inclusive approach of considering each parameter separately.

Indirect parameters are most useful within a geographically limited area. This is due to a tendency of species to compensate for regional differences in climate by utilising locally different aspect or elevation (Guisan & Zimmermann 2000, Prober & Austin 1991). For this reason we have restricted this investigation to the Shoalhaven LGA, although *Cryptostylis hunteriana* does occur more widely. In effect, the trade-off between precision and generality has been resolved in favour of precision.

No attempt has been made to evaluate the predictions of preferred habitat proposed in this paper. Such evaluation is usually effected by means of an independent dataset, or by dividing the existing dataset into two parts; one to generate a set of predictions and the second to test their predictive ability. The difficulty of implementing a formal systematic survey (the best way of acquiring an independent dataset) to establish where *Cryptostylis hunteriana* does and does not occur has already been mentioned above. The second option of dividing the existing dataset into two parts is obviously not suitable for the small datasets which are typically all that are available for rare species.

The approach taken here has the considerable advantage that it can be easily appreciated and understood by non-specialists, such as local government environmental assessment officers. It can also be readily applied in field situations where rapid and straightforward assessments of the likelihood of a rare species being present, must be made; this is particularly important when the species is only observable during a restricted time of the year.

Cryptostylis hunteriana

The Leafless Tongue Orchid, *Cryptostylis hunteriana* Nicholls (family Orchidaceae) (Fig. 1) is a rare, leafless saprophytic terrestrial orchid; based on current information, it appears to be most common in the Shoalhaven area, where the greatest number of populations (25) and the largest population (150+) occur. Other populations in New South Wales are known from the North Coast, Northern Tablelands and Central Coast (Bell 2001). It is also present at three localities in Victoria (Backhouse & Jeanes 1995) and has been recorded from south-east Queensland (Logan 1998). Bell (2001) provides further details on the biology of the species and its habitat preferences on the NSW Central Coast. Two of the three sites described by Bell were considered to belong to the Coastal Plains Scribbly Gum Woodland type (NPWS 2000), while the third was assigned to the Coastal Plains Smooth-barked Apple Woodland type.

Methods

Bioclimatic analysis

The BIOCLIM bioclimatic analysis and prediction system (Nix 1986) has been used to define the study area. The version employed (Chapman 1999) makes use of 16 temperature and rainfall parameters to build a climatic profile for the species based on all the sites where it is known to occur. This profile in turn generates a potential bioclimatic habitat envelope for the Shoalhaven Local Government Area within which the species can be expected to occur, at least in so far as its temperature and rainfall requirements are met.

While BIOCLIM analysis has been used for a wide variety of purposes (Chapman 1999, Lindenmayer Mackey & Nix, 1997, Claridge 2002), it is used here as the first step in a process of identifying preferred habitat for a species. This is based on the recognition that climate is an important determinant of plant species distribution at a broader, regional scale (Prober & Austin 1991, Mackey &Lindenmayer 2001). It is a helpful way of defining a 'study area' within which it is possible to investigate the extent to which other factors, geology and soils, vegetation communities, and species associations influence or reflect the distribution of the species.

Geology and soils

Geological maps of the study area (at a scale of 1:250 000, Geological Survey NSW 1966a, b) were used to determine the geology at each of the 25 sites with known populations of *Cryptostylis hunteriana*. Similarly, soil landscapes were determined from soil landscape mapping (at 1:100 000 scale) carried out as a part of the NSW Comprehensive Regional Assessments Project (Southern Region) (Joint Commonwealth NSW Regional Forest Agreement Steering Committee 1999).

Forest ecosystems

Vegetation mapping was also carried out as a part of the CRA Project (Southern Region) (Thomas, Gellie & Harrison 2000). A combination of aerial photo interpretation (API), validation fieldwork and PATN analysis was used to produce a set of consistent 1:100 000 scale vegetation mapping units (Forest Ecosystems). More recent and detailed vegetation mapping was available for part of the study area (Graham-Higgs 2002a, 2002b) and was used in preference to the earlier CRA mapping, resulting in a few sites being assigned to more appropriate Forest Ecosystems (FEs).

Field sampling procedures

A 400 m^2 (20 × 20 metre) plot was used at each of the validated *Cryptostylis hunteriana* sites, and all vascular plant species recorded: plant species identification and nomenclature follows Harden (1990–1993, 2002) and Harden & Murray (2000), and recent name changes in *Cunninghamia* and *Telopea*.

For the purposes of comparison in the multivariate analyses, a comparable subset of 25 (400 m^2) plots collected during the CRA from FEs (within the BIOCLIM envelope) in which *Cryptostylis hunteriana* has not been recorded historically was used. The classification dendrogram for the CRA data enabled us to select sample plot data for FEs that were separate from (but related to) those FEs with known occurrences of *Cryptostylis hunteriana*. The decision was made to compare the floristics of the known *Cryptostylis hunteriana* sites with a sub-set of the FEs where it has never been found, rather than with the full range of FEs within the BIOCLIM envelope. This comparison was likely to be more informative if it were limited to floristically related FEs: for this reason, vegetation types such as rainforest, wet gully forest and wetlands were not considered. The intention of these comparisons was to explore the detailed differences in floristics between FEs in which *Cryptostylis hunteriana* is known to occur and FEs in which the species has never been recorded.

Multivariate analyses

Two routines in PRIMER (Plymouth Routines in Multivariate Ecological Research) (Clarke & Gorley 2001) have been used to elucidate differences between the species composition of sites with known populations of *Cryptostylis hunteriana* and that of sites from FEs where the species has not been recorded. Ordination by non-metric multidimensional scaling (MDS) provides a two-dimensional spatial model based on species composition. The similarity percentages routine (SIMPER) was used in order to rank the importance of particular species in discriminating between sample sites in which *Cryptostylis hunteriana* was present and those sites in which it had never been recorded.

Results

BIOCLIM analysis

The bioclimatic envelope (Fig. 2) produced from an analysis of the temperature and rainfall variables at all 25 known sites for *Cryptostylis hunteriana* represents an area with the same

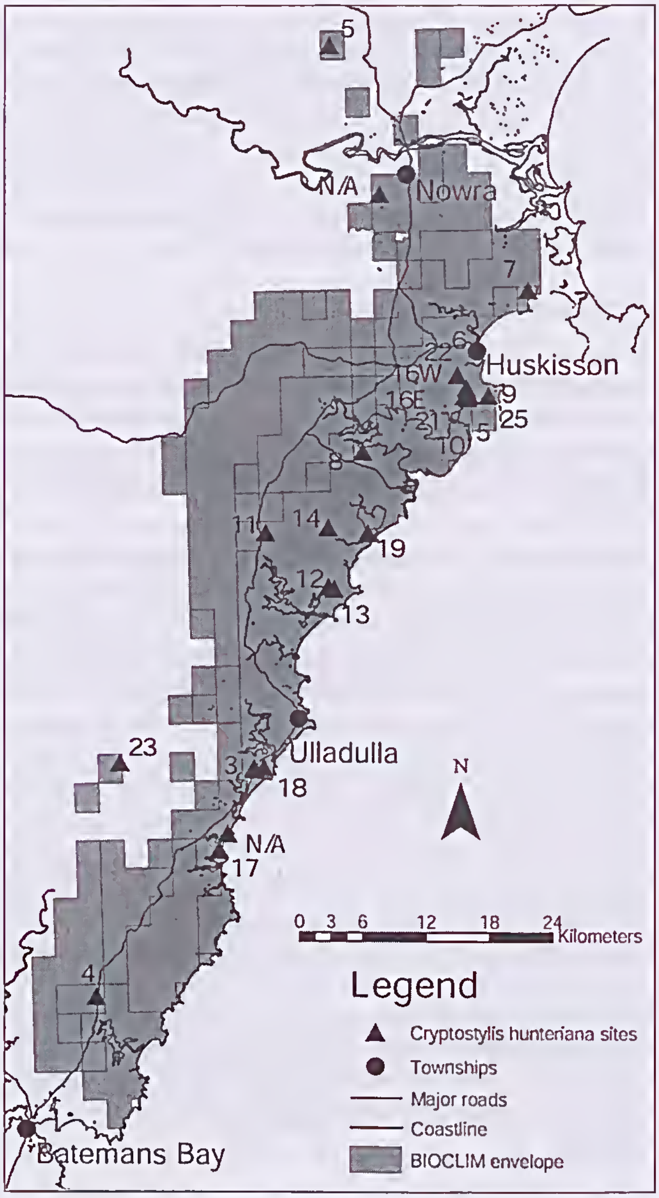
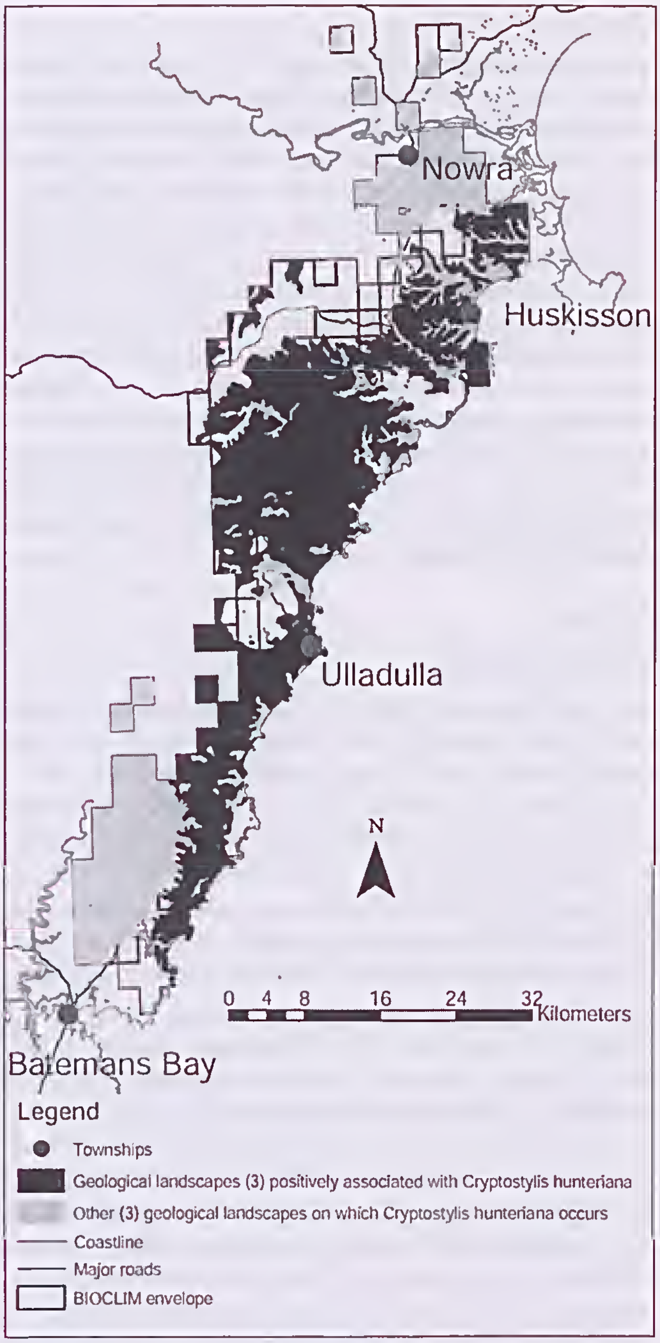


Fig. 2. BIOCLIM potential bioclimatic habitat envelope derived from the climatic profiles at the twenty-five *Cryptostylis hunteriana* sites shown (black triangles).

temperature and rainfall characteristics as the sites with known occurrences of the species. The total area of this envelope is 146 065 ha, representing 31% of the area of the Shoalhaven Local Government Area (468 536 ha).

Correlations with geology and soils

The 25 known occurrences of the *Cryptostylis hunteriana* within the Shoalhaven LGA occur on seven geological units — the Berry, Hawkesbury Sandstone, Conjola and Wandrawandian Formations, as well as areas mapped as Ordovician Sediments, Quaternary Sands and Undifferentiated Sediments (Geological Survey NSW 1966a, 1966b). All of these geological units must be considered to reflect potential habitat for the species.


Nowra
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0 4 8 16 24 32 Kilometers
Legend
● Townships
Geological landscapes (3) positively associated with Cryptostylis hunteriana
Other (3) geological landscapes on which Cryptostylis hunteriana occurs
Coastline
Major roads
BIOCLIM envelope

Fig. 3. Extent of the three geological formations positively associated with *Cryptostylis hunteriana* sites (black) and four additional geological formations on which sites also occur (grey) (superimposed on the BIOCLIM habitat envelope).

However it is possible to distinguish two categories of potential habitat by comparing the number of observed occurrences with the number of expected occurrences of the species in each geological unit, based upon the extent of that geological unit in the BIOCLIM envelope (e.g. 10% of known sites would be expected to occur in a geological unit occupying 10% of the BIOCLIM envelope). The observed occurrences are significantly greater than expected occurrences (g-statistic: $p<0.05$, Sokal & Rohlf 1981) for three of the seven geological formations: Wandrawandian Formation (7 occurrences), Conjola Formation (10 occurrences) and Undifferentiated Sediments (2 occurrences). Taken together, these three formations occupy 81 303 ha or 56% of the study area defined by BIOCLIM and account for 76% of the 25 *Cryptostylis hunteriana* occurrences (Fig. 3).

The remaining 24% of *Cryptostylis hunteriana* occurrences are found on the Berry and Hawkesbury Sandstone Formations, Ordovician Sediments and Quaternary Sands. These geological units total an additional 40 574 ha or 28 % of the study area. Taken together, the potential habitat for the species as defined by geology constitutes 83 % of the study area, a somewhat limited reduction in area in which survey effort would need to be focussed (Fig. 3).

A similar approach taken with the distribution of occurrences of *Cryptostylis hunteriana* in relation to soil landscape mapping reveals the occurrence of the species on nine separately mapped Soil Landscapes. These Soil Landscapes are generally confined to coastal lowland areas which are underlain by sedimentary rocks or unconsolidated deposits, typically in gently undulating terrain. As noted for geological units, when the number of observed occurrences is compared with the number of expected occurrences in each of the soil landscape units, observed occurrences are significantly greater than expected occurrences (g-statistic: $p<0.05$, Sokal & Rohlf 1981) for three of the nine Soil Landscape units. All of these occurrences are located on siltstones or sandstones in gently sloping country, which give rise to soils which can be described as yellow podzolic. In total they account for 72% of the known occurrences, and the area they occupy is 46 884 ha or 32% of the BIOCLIM envelope (Fig. 4).

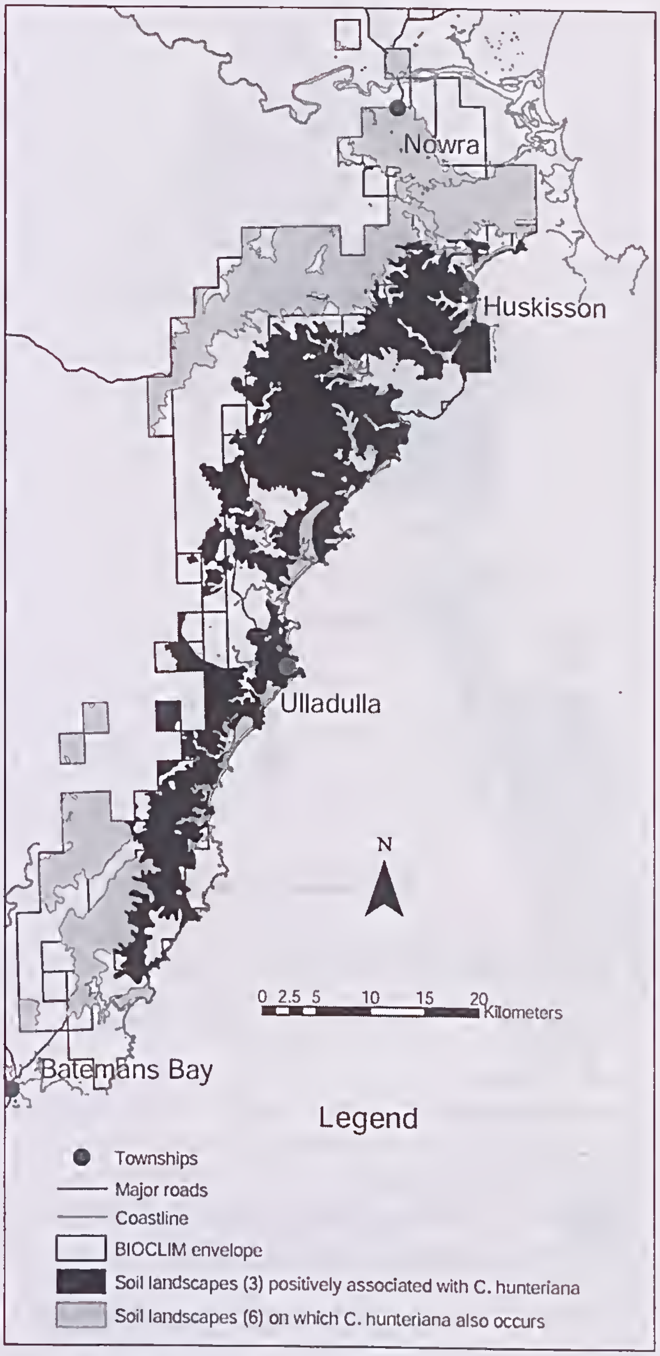
The remaining 28% of *Cryptostylis hunteriana* occurrences are spread over the balance of six Soil Landscape types occupying an additional 39 520 ha or 27 % of the study area. In total, the potential habitat for the species defined by soil landscape is 59% of the study area. This is a significant reduction in the area in which surveys should be focussed in comparison with geological mapping (Fig. 4).

Forest ecosystem relationships

When the relationship between the known occurrences of *Cryptostylis hunteriana* and the vegetation community mapping carried out during the Comprehensive Regional Assessment (CRA) project (Thomas, Gellie & Harrison 2000) is examined, the species is found to be present in six mapped Forest Ecosystems (FEs). Observed occurrences of the species are significantly greater than expected occurrences (g-statistic: $p<0.01$, Sokal & Rohlf 1981) in three of these FEs; short descriptions of these follow:

Forest Ecosystem 2 – Lowland Dry Shrub Forest

This is a medium height forest dominated by *Corymbia gummifera*, sometimes with *Eucalyptus globoidea*, *E. consideniana*, *E. piperita* and *Syncarpia glomulifera* in the Clyde and Shoalhaven catchments. It has a diverse dry shrub understorey, including *Persoonia linearis*, *Banksia spinulosa*, *Acacia obtusifolia*, *Tetratheca thymifolia*, *Leucopogon lanceolatus*, *Lomatia ilicifolia*, *Acacia terminalis*, *Platysace lanceolata*, *Bossiaea obcordata* and *Gompholobium latifolium*. The ground cover stratum contains grasses (*Entolasia stricta*) and herbs (*Patersonia glabrata*, *Dianella caerulea* var. *caerulea* and *Gonocarpus teucrioides*).


Nowra
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Ulladulla
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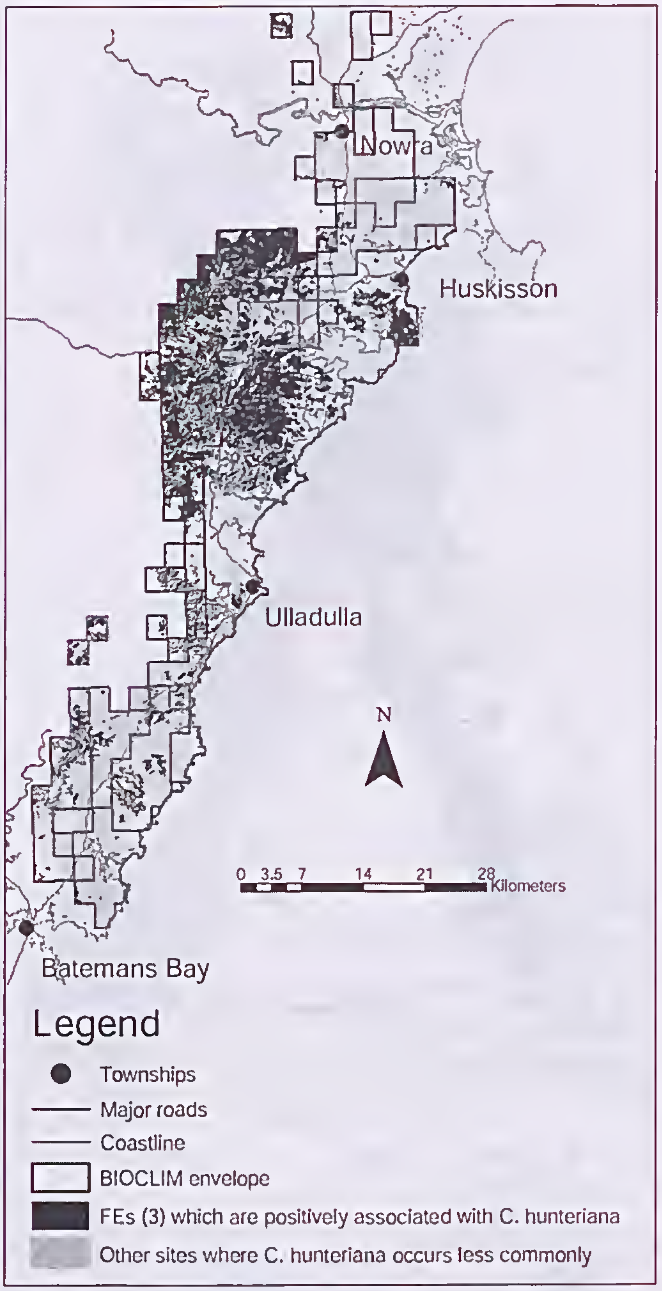
Legend
● Townships
Major roads
Coastline
□ BIOCLIM envelope
■ Soil landscapes (3) positively associated with C. hunteriana
▨ Soil landscapes (6) on which C. hunteriana also occurs

Fig. 4. Extent of the three soil landscape types positively associated with *Cryptostylis hunteriana* sites (black) and six additional soil landscape types on which sites also occur (grey) (superimposed on the BIOCLIM habitat envelope).

Forest Ecosystem 139 – Northern Coastal Hinterland Heath Shrub Dry Forest

This vegetation type comprises mainly medium to low forest dominated by *Eucalyptus sclerophylla* with *Corymbia gummifera* usually present as a sub-dominant. It has a moderately dense heathy shrub layer dominated by species typical of sandstone including *Banksia paludosa*, *Banksia spinulosa*, *Lambertia formosa*, *Hakea dactyloides* and *Leptospermum trinervium*. Ground cover species include *Lepyrodia scariosa* and *Entolasia stricta*.


Nowra
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● Townships
Major roads
Coastline
BIOCLIM envelope
FEs (3) which are positively associated with C. hunteriana
Other sites where C. hunteriana occurs less commonly

Fig. 5. Extent of the three mapped Forest Ecosystems positively associated with *Cryptostylis hunteriana* sites (black) and three additional Forest Ecosystems on which sites also occur (grey) (superimposed on the BIOCLIM habitat envelope).

Forest Ecosystem 140 – Northern Coastal Tall Wet Heath

This is a wet sedge shrubland up to 3 metres high, comprising an open cover of tall shrubs typically including *Hakea teretifolia, Allocasuarina distyla, Leptospermum trinervium* and *L. squarrosum*. It has a diverse intermediate shrub layer, with species including *Sprengelia incarnata, Banksia paludosa, Dillwynia floribunda, Bauera rubioides, Epacris obtusifolia, E. microphylla* subsp. *microphylla, Darwinia leptantha* and *Xanthorrhoea resinifera*. Sedges (*Lepidosperma filiforme* and *Restio fastigiatus*) and herbs (*Actinotus minor*) characterise the ground cover layer.

In total, these three Forest Ecosystems account for 84% of the occurrences of *Cryptostylis hunteriana*, occupying 36 451 ha or 25% of the study area (Fig. 5). The remaining 16% of the species' occurrences are found in Forest Ecosystem 5 (Jervis Bay Lowlands Shrub/Grass Dry Forest), Forest Ecosystem 28 (Coastal Sands Shrub/Fern Forest) and Forest Ecosystem 21 (Northern Foothills Moist Shrub Forest) These types (described below) total 22% of the study area or 32 771 ha.

Forest Ecosystem 5 – Jervis Bay Lowlands Shrub/Grass Dry Forest

This is a forest mainly dominated by *Eucalyptus punctata* along with *Corymbia gummifera* and *Eucalyptus eugenioides*. The shrub layer includes *Allocasuarina littoralis, Daviesia ulicifolia, Melaleuca decora* and *Pimelea linifolia* subsp. *linifolia*. The ground layer contains *Entolasia stricta, Themeda australis, Lomandra multiflora* subsp. *multiflora, Dianella caerulea* var. *caerulea, Lepidosperma laterale, Opercularia diphylla* and *Brunoniella pumilio*.

Forest Ecosystem 28 – Coastal Sands Shrub/Fern Forest

This is a medium to tall forest dominated by *Eucalyptus botryoides*. The shrub understorey consists of *Banksia serrata, Monotoca elliptica, Allocasuarina littoralis, Breynia oblongifolia* and *Acacia longifolia*. The ground cover is predominantly of *Pteridium esculentum, Imperata cylindrica* and *Lomandra longifolia*, along with herbs and twiners such as *Gonocarpus teucrioides, Glycine clandestina* and *Viola hederacea*.

Forest Ecosystem 21 – Northern Foothills Moist Shrub Forest

This is a forest up to 30 m tall dominated by *Corymbia maculata* and *Eucalyptus pilularus* in the southern part of its range, and *Syncarpia glomulifera* and *Eucalyptus saligna* in the northern parts of its range. An intermediate tree layer comprises *Synoum glandulosum, Elaeocarpus reticulatus, Notolaea longifolia, Acacia mabelliae* and *Persoonia linearis*. An intermediate shrub layer comprises *Macrozamia communis, Hibbertia aspera* and *Breynia loblongifolia*. The groundcover is variable and comprises *Gahnia melanocarpa, Lomandra longifolia, Lepidosperma urophorum, Calochlaena dubia* and *Doodia aspera*. Climbing and trailing species include *Pandorea pandorana, Clematis aristata, Smilax australis* and *Morinda jasminoides*.

When Forest Ecosystems are used as a way of defining potential habitat for *Cryptostylis hunteriana*, there is a further increase in the concentration of the known sites, with all sites confined to 47% of the study area (69 224 ha) (Fig. 5). This represents a significant gain in ability to focus survey effort compared with both geological formations and Soil Landscape units.

Interdependence of environmental influences

As a consequence of the hierarchy of environmental influences broadly related to scale, the habitat variables considered in this paper are not independent of one another. Their interdependence can be seen clearly in Table 1 which summarises the information for lithology, soil landscape and vegetation for each site. The Heath Shrub Dry Forest (FE 139) tends to occur on parent material of the Conjola Formation (conglomerate/ sandstone) and the high silica (BFZ) soils derived from it. Coastal Tall Wet Heath (FE 140), in contrast, tends to be found on the Wandrawandian Formation (mudstone/siltstone) and related low silica (GPZ) soils. As can be seen from Table 1, there are exceptions to this pattern and these cross-overs are probably attributable to the presence of sandy layers in the Wandrawandian Formation and silty layers in the Conjola Formation.

Lowland Dry Shrub Forest (FE 2) occurs on a greater variety of parent material including Hawkesbury Sandstone, Conjola Formation, Undifferentiated Sediments (generally alluvial material) and Ordovician Sediments. All of these lithologies (with the possible exception of Ordovician Sediments) give rise to high silica soils.

Forest Ecosystem 5 (Shrub/Grass Dry Forest) and Forest Ecosystem 21 (Northern Foothills Moist Shrub Forest) typically occur on silty/clay soils which, in the case of sites 4 and 20, are derived from Ordovician Sediments and Berry Formation parent material. Site 7 appears somewhat anomalous in that floristically it is closely related to FE 140 which is consistent with the GPZ (2) low silica soil, but not the lithology (Quaternary Sands). This site is close to the boundary with Wandrawandian Siltstone and this may have resulted in some influence on the soil and vegetation of the site.

Forest Ecosystem 28 (Coastal Sands Shrub/Fern Forest) is represented by only one site (24) which is found on high silica soils (BFZ); this site is associated once again with the Conjola Formation. It is interesting that this combination of lithology and soil landscape occurs in association with four of the six FEs in which *Cryptostylis hunteriana* is found; this is a useful reminder that other factors apart from lithology and soil have a significant influence on vegetation and possibly also on the orchid's occurrence.

Multivariate analyses

Surveys undertaken as a part of the CRA vegetation mapping provided floristic data comparable in terms of plot size with data collected from sites at which *Cryptostylis hunteriana* is known to occur. While the CRA surveys were not undertaken specifically to add to our understanding of the occurrence of threatened species, the plot data make it possible to compare the floristics of known sites with floristics of sites located within FEs (related in terms of species composition) for which there are no known occurrences of the species. This comparison was found to be more informative than one with a broader range of FEs, given the sensitivity of Multidimensional Scaling (MDS) analysis to florisitic differences between samples (M. Austin pers. comm.)

The results of the MDS analysis (Fig. 6) show that even with a two-dimensional representation (stress of 0.15 indicating that two dimensions are reasonably adequate), differences in floristic composition between the sites result in good separation between the sites with *Cryptostylis hunteriana* (designated numerically) and those sites from FEs with no known occurrences of *Cryptostylis hunteriana* (designated alphabetically). This suggests distinct floristic differences between sites with and without the orchid and could provide a further means of determining in the field which sites might repay more intensive survey effort for the species.

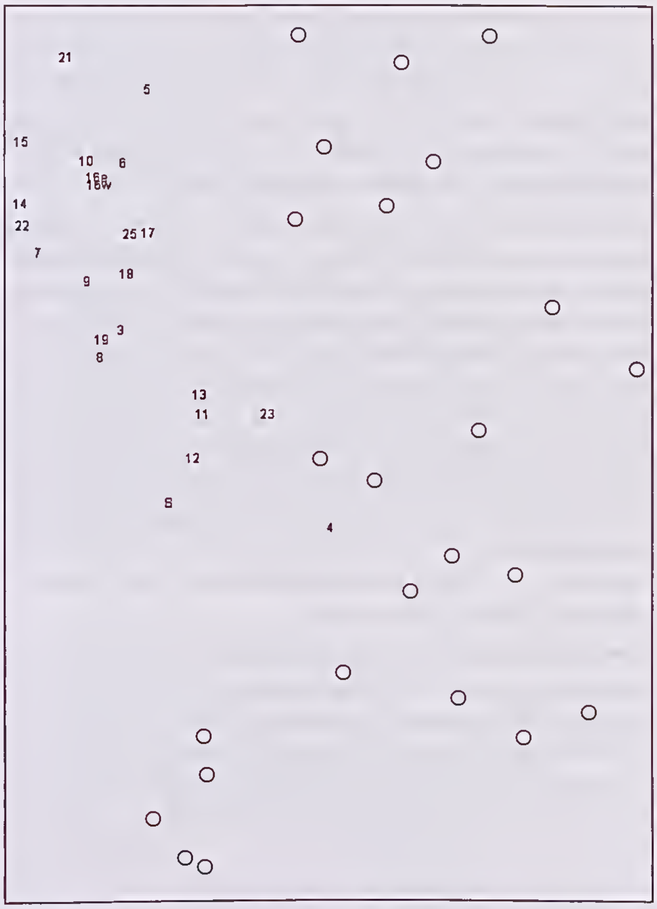

Fig. 6. Multidimensional Scaling representation of the relative position of the sites with *Cryptostylis hunteriana* (numbers) and Forest Ecosystem sites where the species has not been found (○) based on floristic composition.

This possibility is further explored by using the similarity percentages routine (SIMPER) to calculate the percentage frequency of species in both groups of sites. The species most useful as indicators of the possible presence of *Cryptostylis hunteriana* are those with a high frequency of occurrence in the sites where the orchid is present; these species also have a low frequency of occurrence at sites in FEs in which the species has not been recorded. Conversely, species of value as predictors of the likely absence of *Cryptostylis hunteriana* are those with a high frequency of occurrence in FEs where the species has not been recorded and a low frequency of occurrence in sites where the orchid is present. The smaller number of species in the latter category may be due to greater variability in the FEs in which the orchid has not been found (also reflected in the greater spread of these sites on the MDS plot). The species found to be of highest value in this regard are shown in Table 2 together with their frequencies in both groups of sites.

Discussion and conclusions

Since climate is recognised as a fundamentally important environmental factor acting at the broad regional scale, BIOCLIM was a logical starting point in this investigation as a means of defining the study area within the Shoalhaven Local Government area. It has effectively reduced the area of potential preferred habitat for *Cryptostylis hunteriana* from 468 536 ha of the Shoalhaven LGA to a 146 065 ha bioclimatic habitat envelope, which meets the temperature and rainfall requirements of the species determined from the known sites.

It is often the case that rare species exhibit disjunct distributions: *Cryptostylis hunteriana* is a good illustration of this with occurrences outside the Shoalhaven LGA on the Central Coast of New South Wales as well as in Victoria and Queensland. While it would have been possible to generate a bioclimatic envelope based on all of these sites, the gain in generality would have been at the expense of precision, because over such a large geographic range the local environments utilised by the species would differ significantly. As a general rule, we believe that where disjunct distributions occur, the consideration of each region separately will lead to a more effective delineation of preferred habitat for rare species.

It is noteworthy in this regard that previous habitat descriptions from the NSW Central Coast, Victoria and Queensland (Bell 2001) consistently refer to sandy soils. South Coast occurrences expand information on preferred habitat to include silt/clay loam soils developed on low silica silt/mudstone lithologies of Permian and Ordovician age. It may also be significant in terms of the distributional behaviour of the species over its considerable range that the Central Coast occurrences are all in woodland communities (Bell, 2001) which correspond broadly to the Forest Ecosystems 2 and 139 in this study, while the South Coast and Victorian habitats encompass both woodland and heath.

Within the Shoalhaven LGA, the FEs in which no occurrences of *Cryptostylis hunteriana* have been found to date tend to occur on Permian and Ordovician mudstone/siltstone lithologies, with their associated low silica soils or on granitic parent material. They are also more likely to occur some distance from the coast, at higher elevations and in more sheltered and moist topographic positions and aspects.

The comparison of lithology, soil landscape and vegetation as alternative approaches to the definition of preferred habitat has been both useful and revealing. While these variables are clearly interrelated, they differ markedly in the degree to which they restrict the areal extent of habitat warranting further intensive investigation. While any of the three could be used as a guide in focusing future survey or in evaluating individual sites for their potential to support populations of *Cryptostylis hunteriana*, there are significant gains to be made in using vegetation when all of the known sites are restricted to FEs covering 47% of the study area. This is a significant reduction in the area of potential habitat when compared with lithology (where the preferred habitat based on all of the known sites is 83% of the study area) or with soil landscape (with all known sites occupying 59% of the study area).

Table 1. Interrelationships between geology, soil landscape and forest ecosystem for the 25 known occurrences of *Cryptostylis hunteriana*. * Bold type indicates a statistically significant association between the geology, soil landscape or forest ecosystem units and *Cryptostylis hunteriana*.

Site	Geology*	Soil Landscape	Forest Ecosystem
1	**Conjola Fm**	**BFZ**	**139**
2	**Conjola Fm**	**BHZ**	**139**
3	**Conjola Fm**	**BFZ**	**139**
6	**Wandrawandian Fm**	**GPZ**	**139**
8	**Conjola Fm**	**BFZ**	**139**
17	**Conjola Fm**	**BFZ**	**139**
18	**Conjola Fm**	**BFZ**	**139**
19	**Wandrawandian Fm**	**GPZ**	**139**
9	**Conjola Fm**	**BFZ**	**140**
10	**Wandrawandian Fm**	**GPZ**	**140**
14	**Conjola Fm**	**BFZ**	**140**
15	**Wandrawandian Fm**	**GPZ**	**140**
16	**Wandrawandian Fm**	**GPZ**	**140**
21	**Wandrawandian Fm**	**GPZ**	**140**
22	Quaternary Sands	ABZ	140
25	**Wandrawandian Fm**	**GPZ**	**140**
5	Hawkesbury Ss	BAZ	2
11	**Conjola Fm**	**BFZ**	2
12	**Undifferentiated Seds**	**ULZ**	2
13	**Undifferentiated Seds**	**ULZ**	2
23	Ordovician Sedim	TJZ	2
4	Ordovician Sedim	TJZ	21
7	Quaternary Sands	GPZ (2)	5
20	Berry Fm	NOZ	5
24	**Conjola Fm**	**BFZ**	**28**

For each of the three variables a distinction has been made between two levels of preferred habitat. The testing for significance of the difference between the number of observed vs. expected occurrences in the different FEs provides a basis for this distinction. These two levels may be regarded as more optimal and less optimal habitat. The fact that all but one of the sites with populations > 7 individuals are found in FEs which have a significantly greater number of observed than expected occurrences lends weight to this distinction. Nevertheless, it must be recognised that all known sites carry information about where additional populations might be found. In addition, occurrences that are not in optimal environments may be unusual or restricted in a way that makes them important for conservation of this species.

The use of vegetation in this study as a means of defining preferred habitat and guiding survey has been further refined by making use of floristic data from the sites where *Cryptostylis hunteriana* is known to occur. We know, on the basis of the CRA mapping, that these sites are confined to six FEs. The multivariate analyses used in this study have proven very helpful in comparing site floristics for these six FEs with site floristics for related FEs in which the orchid has not been found. The MDS analysis shows clearly that, on the basis of floristics, there is good separation between these six FEs and other related FEs in the study area. The PRIMER analysis identifies a set of indicator species characterising the differences between the two groups of FEs.

These species provide a further tool which can be used in the field to decide whether a particular area should be regarded as preferred *Cryptostylis hunteriana* habitat. Their presence at a site can serve as a useful confirmation that the site does in fact constitute preferred habitat. Conversely, the absence of these species (or the presence of species indicative of FEs that are not preferred habitat for the species) may indicate that the species is less likely to occur there.

Table 2. Species with a preference for sites with or without *Cryptostylis hunteriana* (expressed as a high frequency of occurrence at one group of sites and a low frequency of occurrence at the other group of sites).

Species	Frequency	
	Sites with *Cryptostylis hunteriana*	Sites without
Lomandra filiformis	0.86	0.04
Pimelea linifolia	0.86	0.15
Xanthosia tridentata	0.82	0.04
Lomandra obliqua	0.82	0.23
Lambertia formosa	0.82	0.12
Dampiera stricta	0.73	0.04
Hakea dactyloides	0.73	0
Entolasia marginata	0.64	0.12
Isopogon anemonifolius	0.64	0.04
Kunzea capitata	0.64	0
Dianella caerulea	0	0.65
Lepidosperma laterale	0.09	0.50
Persoonia linearis	0.09	0.50

It is important to stress that in making this comparison the 25 known sites represent an independent data-set superimposed on the CRA mapping. No new occurrences of *Cryptostylis hunteriana* were found during the CRA survey. Though the survey work was largely, if not entirely, carried out at times of the year when the species would not have been detected, it is highly unlikely that survey work at more favourable times of the year would have discovered any new populations, given the limited areas surveyed (400 m^2 plots) and the rarity and cryptic nature of the species.

We are fully aware that these preliminary steps toward identifying preferred habitat for *Cryptostylis hunteriana* represent hypotheses which remain to be tested. It is important to recognise that as such tests cannot be done for rare or cryptic species such as this by systematic sampling; a different approach is needed. The framework presented in this paper should be seen as a valuable starting point in a process of successive approximation for the identification of preferred habitat. Ideally, it will make it possible to more readily assess the significance of new occurrences as they are found, and to expand and refine our understanding of habitat preferences.

There are other lines of enquiry which could also be followed to refine habitat preferences for this species. *Cryptostylis hunteriana* is commonly observed to occur in relatively open areas in the Forest Ecosystems in which it is found. Better understanding of the significance of disturbance regimes and competition in determining where the species occurs could be helpful in predicting its presence. The recognised close relationships between orchid species and their pollinators, and with soil fungi, also need to be investigated. It is possible that areas of habitat which are otherwise favourable may be unoccupied because of the absence of a particular pollinator or soil fungus. The fungi associated with saprophytic orchids (ectomycetes) may have alternative host species (Peter McGee pers. comm.) whose presence or absence could also influence *Cryptostylis hunteriana* occurrence.

Several limitations are intrinsic to the approach taken here. The first is the scale at which the three habitat variables were mapped. Mapping at a scale of 1:100 000 is, by its very nature, generalised; however, being all that was available, it was accepted as a useful starting point. More detailed mapping of vegetation for the Shoalhaven LGA is currently underway; and could be used to refine the definitions of preferred habitat presented here. A possible source of such error in mapping at this scale is that a site is incorrectly assigned to a geological, soil landscape or Forest Ecosystem unit where it falls close to a mapping boundary. Sites were checked for all three variables. With regard to geology and soil landscapes, since no independent information was available on these parameters, a conservative position was adopted and no reallocations were made. In the case of FEs, detailed floristic data available for the sites enabled an independent evaluation to be made of the mapping validity. Two sites were considered to be incorrectly mapped on the basis of floristic data. Site X was reassigned from FE 24 to FE 5 (the boundary between these two FEs was 0.02 km from the site). Site W was reassigned from FE 138 to FE 21 also on the basis of a much closer floristic match even though the mapping did not record the presence of the FE in the vicinity of the site.

Existing records constitute a valuable source of information on habitat preferences, although we recognise that there are limitations. We had 25 reliable records for *Cryptostylis hunteriana* extending as far back as thirty years and have endeavoured to show how maximum use can be made of such information to identify preferred habitat and for progressively refinement. Systematic survey work, however desirable, is likely to remain prohibitively expensive and is likely to yield little additional information relative to the effort expended.

We would stress that the results of this study should be used only as an indicator of the types of habitat which are likely to repay further survey effort. They should not be used to argue that no survey is required in areas which have not been shown to be preferred habitat for the species. This is particularly the case for areas subject to applications to clear or substantially modify native vegetation. It is necessary to continue to gather data, either to confirm hypotheses or to expand understanding of what constitutes preferred habitat for this species.

We recommend that future survey work for *Cryptostylis hunteriana* within the Shoalhaven Local Government Area should:

- Concentrate on areas mapped as one of the six Forest Ecosystems with which *Cryptostylis hunteriana* is associated within the BIOCLIM envelope;
- Within these Forest Ecosystems, particular attention should be paid to sites where species positively associated with the orchid are found to be present; and
- Searching elsewhere should continue, albeit at a lower level of intensity.

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Distribution and habitat of the vulnerable tree species, *Angophora inopina* (Myrtaceae), on the Central Coast of New South Wales

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Abstract: *Angophora inopina* is a vulnerable tree species occurring principally in Wyong and Lake Macquarie local government areas on the Central Coast, with disjunct populations as far north as Bulahdelah on the North Coast of NSW. The largest and most intact stands occur within the Wyee-Morisset areas although even here significant fragmentation is evident. North of Toronto, there are small and scattered residual populations as far as Barnsley near West Wallsend in Lake Macquarie. A total area of occupied habitat of approximately 1500 ha is estimated.

Cluster analysis of floristic information showed that *Angophora inopina* occurs within three broad habitat types within the Central Coast bioregion, centred mainly on the Gorokan, Doyalson and Wyong soil landscapes. Hybrid forms of the species also occur on the Cockle Creek landscape in northern Lake Macquarie. Most stands are evident within open woodland/forest vegetation where *Eucalyptus haemastoma*, *Corymbia gummifera*, and *Eucalyptus capitellata* dominate with *Angophora inopina*. Other populations occur in wet heath, and swamp woodland environments where sedge species are characteristic.

Conservation of *Angophora inopina* will be most effectively and efficiently achieved if ecological processes that operate across the landscape are maintained. Processes such as fragmentation, altered fire regimes or invasion of habitat by exotic species must be managed in the long-term. These are all significant threats to this species, and will best be effectively managed in the larger remnants in a landscape approach. Such threats are generally associated with urban and agricultural expansion in the area, and these are therefore the most pressing issues to be managed.

***Cunninghamia* (2004) 8(4): 477–484**

Introduction

Angophora inopina K.D. Hill (family Myrtaceae) is a small tree species previously thought to be restricted to the Wyee–Charmhaven area of the New South Wales Central Coast (Benson & McDougall 1998), but now known to extend as far north as Bulahdelah on the mid North Coast (Fig. 1). Prior to its formal description (Hill 1997), *Angophora inopina* had been confused with the common *Angophora floribunda*, and was at times referred to as an unusual form of that species (e.g. Payne & Duncan 1999). In May 1998, the NSW Scientific Committee listed *Angophora inopina* as Vulnerable (Schedule 2) on the NSW *Threatened Species Conservation Act 1995* (TSC Act), in recognition of its fragmented and restricted distribution, and the threatening processes acting upon its habitat. At the time of listing, little information was available on the distribution of the species, or of its conservation status within proclaimed reserves. *Angophora inopina* has also been included on the schedules of the Commonwealth *Environment Protection & Biodiversity Conservation Act 1999*.

Hill (1997) reported the habitat of this species to be open dry sclerophyll woodland of *Eucalyptus haemastoma*, *Corymbia gummifera* and *Eucalyptus capitellata*, over a dense shrubby understorey. No other information on habitat or distribution has been published, apart from brief entries in floras and eucalypt identification keys (e.g. Hill 2002, Brooker et al.

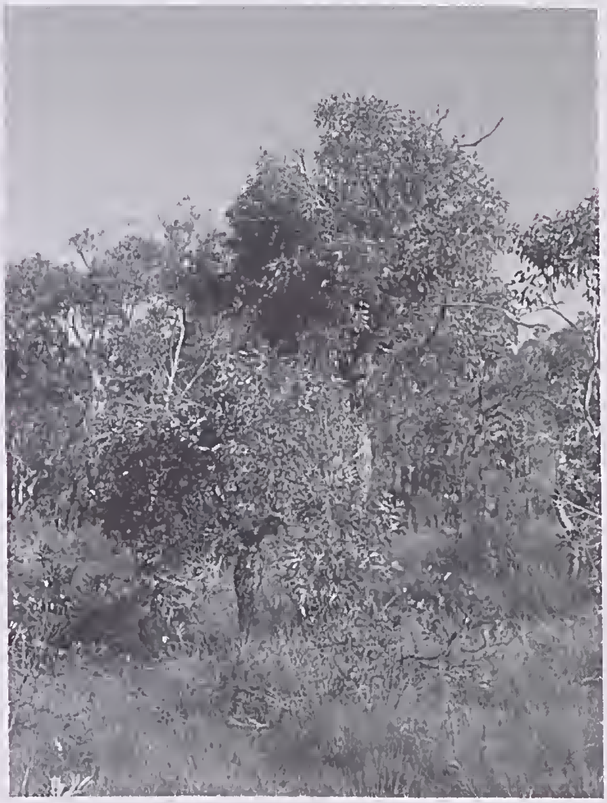

Fig. 1. A mature specimen of *Angophora inopina*, illustrating the typical habit across most of its range.

2002). Tierney (2004) has recently examined the reproductive characteristics, and concluded that although most populations will be resilient to low recruitment levels in the short-term, understanding and monitoring of population structural change is a priority for this species in the long-term.

This paper, based on survey and mapping work for Wyong and Lake Macquarie councils (Bell 2001a) describes the extent of *Angophora inopina* populations within the NSW Central Coast and outlines the habitat for the species in this region.

The study area

The Central Coast region lies approximately 100 km north-east of Sydney, within the Sydney Basin bioregion (Thackway & Cresswell 1995), and the Central Coast botanical subdivision (Anderson 1961). The study area includes Wyong and Lake Macquarie local government areas (Fig. 2). Existing conservation reserves within these two LGAs include all or parts of Munmorah, Glenrock, Lake Macquarie and Jilliby State Conservation Areas, Watagans and Wyrrabalong National Parks, and Pulbah Island, Tingira Heights and Awabakal Nature Reserves.

The NSW Central Coast falls within a warm temperate climatic zone, with a maritime influence near the coast, and experiences warm wet summers and cool dry winters. Rainfall generally peaks in late Summer and early Autumn, although local variations due to topography are evident. Annual average rainfall ranges from 1207 mm at Kulnura to 1589 mm in Olney State Forest. Temperatures range from a daily average low of 4°C in July, to a high of 27°C in January and February (Bureau of Meteorology 2001).

Geologically the study area is part of the Hornsby Plateau subdivision of the Sydney Basin, and is comprised of consolidated sediments of the Triassic Hawkesbury and Triassic Narrabeen series (Bembrick et al. 1980). On the Central Coast lowlands only the lower sections of the Narrabeen Group outcrop, comprising the Clifton Sub-Group, where the Patonga Claystone, Tuggerah Formation, Munmorah Conglomerate and Dooralong Shale have been recognised (Uren 1980). Extensive areas of unconsolidated alluvial soils occur along major valleys and streams, and large deposits of Quaternary marine and aeolian sands occur along the coastline. Soil landscapes have been described by Murphy (1993) and Murphy and Tille (1993).

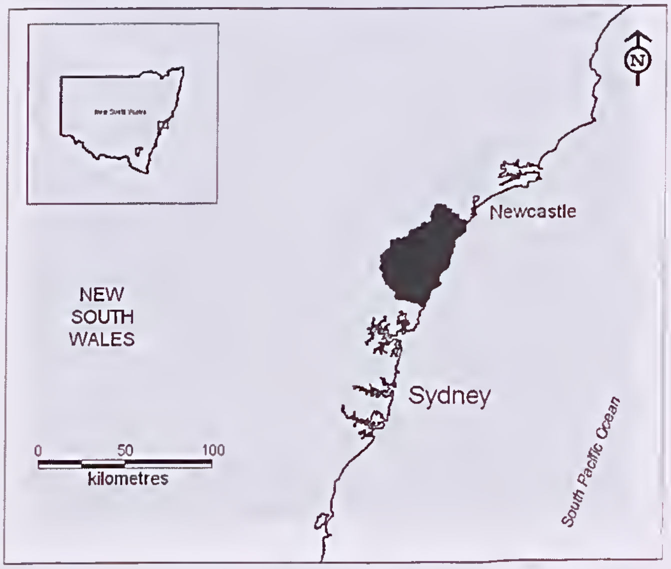

Fig. 2. Location of the Central Coast study area

Methods

Mapping occupied habitat

General observations on the Central Coast distribution of *Angophora inopina* indicated that the species most commonly occurred on the Doyalson (do) and Gorokan (gk) soil landscapes of Murphy (1993), or in shallow alluvial soils of the Wyong (wy) soil landscape (Bell 1996, Hedley 1997, Hedley & Branwhite 1998, Bell 1999, Leonard 2001). Records of environmental consultants and other botanists, and data from the NSW National Parks and Wildlife Service wildlife atlas provided initial reference points for ground searches. Populations and sub-populations were initially mapped at 1:25 000 scale following extensive ground truthing within these targeted soil landscapes, and then revised with larger scale mapping (1:16 000) after assessments of each site were made. Population extent was mapped using a handheld GPS for identification of stand boundaries, with polygons marked directly onto topographical map sheets.

Rapid habitat assessment

A rapid habitat assessment was carried out at most *Angophora inopina* stands. This process involved the collection of a range of environmental variables from each discrete sub-population, which (for the purpose of this study) was defined as one which was separated by at least 100 m from any other occurrence of the species. Separations due to anthropogenic sources (e.g. clearing, road corridors etc.) were not considered in this definition. Populations were defined following the rationale of Keith et al. (1997), whereby distinct populations can be deemed as those which are separated by a geographical discontinuity of more than 1 km.

Variables examined included estimated population size, weed abundance, erosion, fire history, general access and trail condition, subjective health of adult *Angophora inopina* trees and reproductive status, population structure, population fragmentation, vegetation and habitat homogeneity, extent of grazing or other disturbance and degree of hybridisation. Hybrid forms of the species were deemed as those plants showing more coriaceous leaves when compared to specimens at the type location, petioles greater than 8 mm in length, and exhibiting a habit generally more akin to *Angophora floribunda* than *Angophora inopina*. Experience had shown that such specimens were often but not always growing in deeper alluvial soils. Individual scores for each

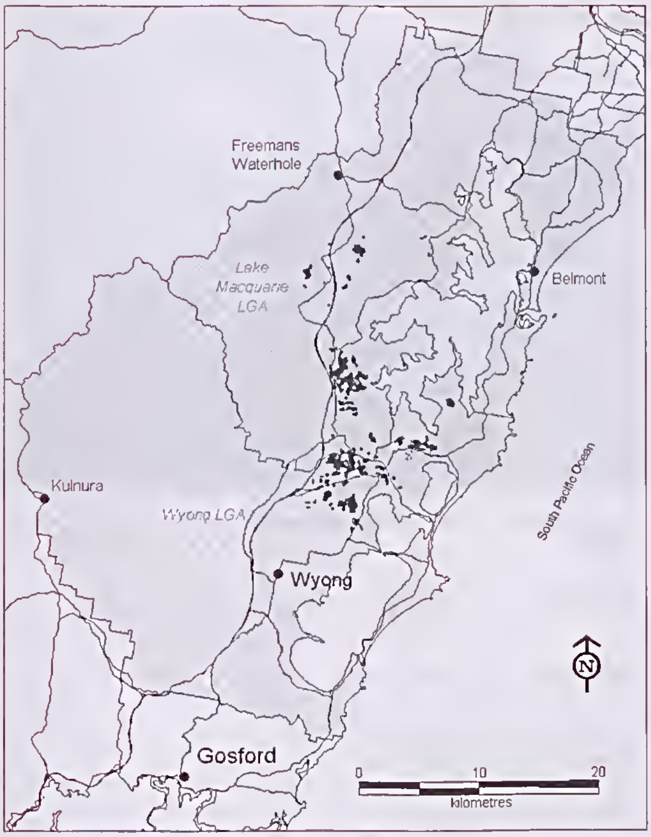

Fig. 3. Occupancy area of *Angophora inopina* (dark shading) on the Central Coast.

attribute in each sub-population were noted on a standard pro-forma field sheet, and then tallied to provide a habitat score. The maximum score of 44 would represent very high habitat quality.

Classification of habitat

Classification of *Angophora inopina* habitat was undertaken using plot-based floristic data from sites chosen as representative of the main habitats. Much of this data was collected for the survey and mapping program undertaken by the NSW National Parks and Wildlife Service for the bioregional study of the vegetation occurring in the lower Hunter Valley and Central Coast (NPWS 2000). All studies incorporated the recording of all vascular plant species within 0.04 ha plots (nominally 20 m × 20 m quadrats). For each taxa present, modified Braun-Blanquet cover abundance values (1–6) were applied to quantify abundance (Poore 1977). Broad structural data also collected at each site included strata (vegetation layers) present, height and projected foliage cover, and dominant species for each strata. Multivariate statistical analysis using the *PATN* clustering program (Belbin 1995a, 1995b) was performed to identify the floristic associates of *Angophora inopina*, and to determine the relationships between various stands.

Results

Mapping of known populations

Approximately 1500 ha of *Angophora inopina* habitat has been mapped for Wyong and Lake Macquarie LGAs. Most populations lie within the Central Coast Lowlands physiographical region of Murphy (1993), extending for 35 km (approximately the Wallarah catchment to Barnsley). This habitat occurs across a range of land tenures, but is highly fragmented across the landscape, existing in small stands of <0.5 ha to areas as large as 300 ha (Fig. 3). The total north–south distributional extent for the species is 120 km, when northern populations around Karuah and Bulahdelah are considered (Bell 2001a).

Rapid habitat assessment

Thirty-eight sub-populations of *Angophora inopina* were assessed for habitat quality. A maximum habitat score of 38 (out of a possible 44) was achieved by stands near Wyee, while the minimum score of 21 occurred in small fragmented sub-populations where hybridisation with *Angophora floribunda* was evident. These results have been incorporated into a conservation strategy for the species, whereby areas identified as supporting higher quality habitat have been targeted for inclusion in regional conservation networks and green corridors.

Classification of habitat

Cluster analysis of forty-two floristic sites from the Central Coast revealed that *Angophora inopina* occurs most frequently in one of three main vegetation communities: *Eucalyptus haemastoma* Woodland/Forest (Community 1), containing the bulk of the population, and with lesser occurrences in *Hakea teretifolia – Banksia oblongifolia* Wet Heath (Community 2) and *Eucalyptus resinifera – Angophora costata* Sedge Woodland (Community 3). Table 1 shows plant species common to the three communities, and indications of their relative abundance in each, derived from examination of two-way tables.

In addition, representation of *Angophora inopina* in other geographically restricted vegetation types not described here may also have significant conservation value. These include an *Angophora inopina* × *Angophora floribunda – Melaleuca* Thicket Forest from the northern Lake Macquarie area, where hybrid zones of *Angophora inopina* × *Angophora floribunda* occur with *Melaleuca linariifolia*, *Melaleuca nodosa*, *Melaleuca decora* and *Eucalyptus resinifera*, generally on the Cockle Creek (cc) soil landscape of Matthei (1995). Similar areas occur in sections of the Porters Creek wetland catchment, although here specimens are closest to pure *Angophora inopina*. Ecotonal zones also exist in parts of both the Doyalson (do) and Gorokan (gk) soil landscapes where drainage is generally poor, and there exists a mix of wet and dry species. Often this occurs along the transition from Community 1 to Communities 2 and 3, and is manifested in

Table 1. Indicator species for defined communities supporting *Angophora inopina*.

Growth Form	Species	Community 1	Community 2	Community 3
Canopy	*Angophora costata*	rare		abundant
	Angophora inopina	abundant	common	abundant
	Corymbia gummifera	abundant		
	Eucalyptus capitellata	common		
	Eucalyptus haemastoma	abundant		
	Eucalyptus resinifera			abundant
	Eucalyptus robusta			rare
	Melaleuca decora			rare
	Melaleuca sieberi		common	abundant
Shrub	*Acacia elongata*			abundant
	Acacia longifolia			common
	Banksia oblongifolia	abundant	abundant	
	Banksia spinulosa var. *collina*	abundant		rare
	Epacris obtusifolia		common	rare
	Epacris pulchella	common	rare	
	Gahnia clarkei			abundant
	Grevillea sericea	common	common	
	Hakea laevipes	abundant		
	Hakea teretifolia		abundant	common
	Isopogon anemonifolius	abundant		
	Lambertia formosa	abundant		
	Leptospermum polygalifolium	rare	common	common
	Leptospermum trinervium	common		
	Melaleuca nodosa			rare
	Melaleuca thymifolia		common	abundant
	Persoonia levis	common		
	Petrophile pulchella	abundant		
	Pimelea linifolia subsp. *linifolia*	abundant		rare
	Pultenaea villosa			abundant
Groundcover	*Anisopogon avenaceus*	common		
	Aristida ramosa	common		
	Aristida vagans	common		
	Aristida warburgii	common	abundant	
	Chorizandra cymbaria			common
	Dichelachne micrantha			common
	Echinopogon caespitosus			common
	Entolasia stricta	abundant	rare	common
	Empodisma minus			abundant
	Eragrostis brownii	common	common	
	Hibbertia vestita	abundant		
	Leptocarpus tenax		abundant	common
	Lepyrodia scariosa		common	abundant
	Lindsaea linearis	common	rare	common
	Panicum simile	common	common	
	Patersonia sericea	abundant		
	Ptilothrix deusta	abundant	rare	
	Schoenus brevifolius		abundant	abundant
	Selaginella uliginosa		common	abundant
	Themeda australis	common	common	abundant
	Xanthorrhoea latifolia	abundant		

large areas of sedges, such as *Lepyrodia scariosa* and *Ptilothrix deusta*, in the ground layer. In a small number of locations at Chain Valley Bay and Charmhaven, *Angophora inopina* occurs in open forest dominated by *Eucalyptus racemosa*, *Corymbia gummifera* and *Eucalyptus capitellata*. Different vegetation types also support *Angophora inopina* in the Karuah and Bulahdelah areas of the North Coast, occurring mostly on Carboniferous sandstones and sediments (Bell 2000).

Community 1: *Eucalyptus haemastoma* Woodland/Forest (Fig. 4)

Description: *Eucalyptus haemastoma* Woodland/ Forest is the most widespread in the sub-region, occurring generally on the Doyalson (do) and Gorokan (gk) soil landscapes of Murphy and Tille (1993), which emanate from Munmorah Conglomerates and the Tuggerah Formation. Variation is principally related to structure and time since last fire, with plots subjected to recent fire (<5 years) generally distinguishable from those of a greater fire-free period. Structure varies from a very low mallee heath (at San Remo, possibly as a result of repeated disturbance over many years), through open woodland–woodland (the vast majority of sites), to open forest. *Angophora inopina* often forms a co-dominant throughout much of the mapped distribution of this type, in association with *Eucalyptus haemastoma* and *Corymbia gummifera*. This vegetation type equates to the Coastal Plains Scribbly Gum Woodland (MU31) of NPWS (2000).

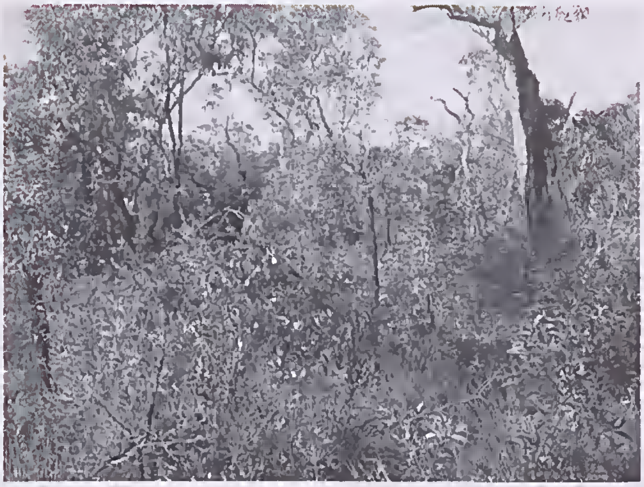

Fig. 4. *Eucalyptus haemastoma* Woodland/ Forest (Community 1) near Gwandalan.

Structure: Canopy: 8–22 m, 20–40 % cover; Mid-storey: 3–5 m, 10–20 % cover; Lower: 0.3–1.5 m, 40–80 % cover.

Canopy: *Eucalyptus haemastoma, Corymbia gummifera, Angophora inopina, Eucalyptus capitellata, Angophora costata*

Shrubs: *Banksia oblongifolia, Banksia spinulosa* var. *collina, Hakea laevipes* subsp. *laevipes, Isopogon anemonifolius, Lambertia formosa, Persoonia levis, Petrophile pulchella, Pimelea linifolia* subsp. *linifolia, Leptospermum trinervium, Xanthorrhoea latifolia* subsp. *latifolia, Xanthorrhoea resinifera*

Low shrubs: *Epacris pulchella, Hibbertia vestita*

Herbs/ Ferns: *Patersonia sericea, Linsaea linearis*

Sedges: *Ptilothrix deusta*

Grasses: *Aristida ramosa, Themeda australis, Aristida vagans, Anisopogon avenaceus, Entolasia stricta*

Community 2: *Hakea teretifolia – Banksia oblongifolia* Wet Heath (Fig. 5)

Description: A low, wet heath with occasional emergents of *Angophora inopina* or *Melaleuca sieberi*. Variation within this type is heavily dependant on soil structure, principally depth to the water table, fire history and the extent of impeded drainage present. Consequently, floristic variation is greater than in other communities. The distribution of *Hakea teretifolia / Banksia oblongifolia* Wet Heath is linked to the occurrence of embedded siltstone or mudstone lenses in the Munmorah Conglomerate and Tuggerah Formation within Clifton sub-group geology, and corresponds to part of the Doyalson (do5) and Gorokan (wo3) soil landscapes of Murphy and Tille (1993). *Angophora inopina* here is generally restricted to scattered occurrences, in association with varying densities of *Hakea teretifolia* and *Banksia oblongifolia*. During regional classification studies, this type was not clearly defined, but is probably included within the Coastal Plains Scribbly Gum Woodland (MU31) of NPWS (2000).

Structure: Canopy: 2–4 m, 5–10 % cover; Mid-storey: 0.5–1.7 m, 60–95 % cover; Lower: 0.1–0.3 m, 5–20 % cover.

Canopy: *Angophora inopina, Melaleuca sieberi*

Shrubs: *Hakea teretifolia, Banksia oblongifolia, Epacris obtusifolia, Leptospermum polygalifolium, Grevillea sericea*

Low shrubs: *Epacris pulchella*

Herbs/ Ferns: –

Sedges: *Lepyrodia scariosa, Leptocarpus tenax, Schoenus brevifolius*

Grasses: *Aristida warburgii, Panicum simile, Entolasia stricta, Eragrostis brownii, Themeda australis*

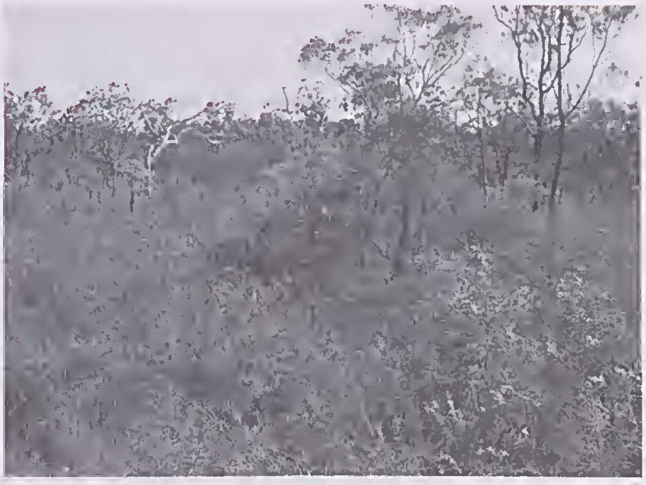

Fig. 5. *Hakea teretifolia – Banksia oblongifolia* Wet Heath (Community 2) near Wyee.

Community 3: *Eucalyptus resinifera – Angophora costata* Sedge Woodland (Fig. 6)

Description: Located in shallow drainage lines high in the catchment, this vegetation type is characterised by a very open canopy and a dense understorey of sedge species. *Eucalyptus resinifera* and *Melaleuca sieberi* typically dominate the canopy, with the occasional *Eucalyptus robusta* and scattered *Angophora inopina*. This type appears to be associated with shallow areas of the Wyong (wy) soil landscape, and/ or parts of the Doyalson (do4) and Gorokan (gk4) soil landscapes. The equivalent regional map unit is Riparian Melaleuca Swamp Woodland (MU42) (NPWS 2000).

Structure: Canopy: 10–20 m, 20–40 % cover; Mid-storey: 3–8 m, 20–40 % cover; Lower: 0.3–1.0 m, 70–100 % cover.

Canopy: *Eucalyptus resinifera, Angophara inopina, Angophora costata, Melaleuca sieberi, Eucalyptus robusta, Melaleuca decora*

Shrubs: *Melaleuca sieberi, Melaleuca nodosa, Pultenaea villosa, Acacia elongata, Acacia longifolia*

Low shrubs: *Melaleuca thymifolia*

Herbs/ Ferns: *Selaginella uliginosa*

Sedges: *Lepyrodia scariasa, Gahnia clarkei, Empodisma minus, Chorizandra cymbaria, Schoenus brevifolius*

Grasses: *Entolasia stricta, Themeda australis, Echinopogon caespitosus, Dichelachne micrantha*

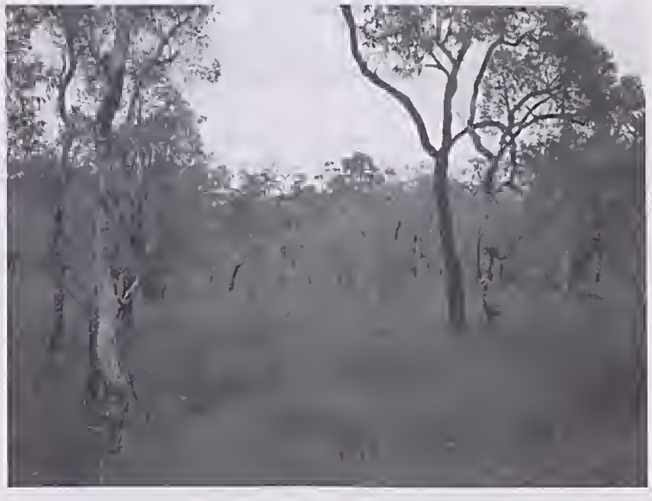

Fig. 6. *Eucalyptus resinifera – Angophora costata* Sedge Woodland (Community 3) near Morisset.

Discussion

Broadly speaking, the Central Coast populations of *Angophora inopina* correlate well with the distribution of Clifton sub-group geology, principally the Munmorah Conglomerates, and approximately 1500 ha of habitat has been mapped on the Central Coast. Sizeable populations in intact and contiguous bushland remain in the Morisset and Wyee areas; this area also supports those stands of the highest quality. In other areas the species has been highly fragmented by urban and rural development, surviving in remnant stands of vegetation within its mapped range (e.g. Morisset, Wyee, Charmhaven).

The most common vegetation community supporting the species is the *Eucalyptus haemastoma* Woodland/ Forest (Community 1), which occupies relatively extensive areas of the Central Coast, principally to the immediate south and west of Lake Macquarie. Within this landscape, smaller areas of *Hakea teretifolia – Banksia oblongifolia* Wet Heath (Community 2) and *Eucalyptus resinifera – Angophora costata* Sedge Woodland (Community 3) occur. To date, development pressures have occurred within these areas, along ridgetops and gentle slopes, particularly in Communities 1 and 2, but also impinging on areas supporting Community 3, which is restricted to shallow drainage lines and subject to catchment and upslope disturbances. In the regional study of NPWS (2000), *Angophora inopina* occurred within the Coastal Plains Smooth-barked Apple Woodland (map unit 30), and the Riparian Melaleuca Swamp Woodland (map unit 42), but was considered a diagnostic species only for map unit 31 (Coastal Plains Scribbly Gum Woodland), supporting the results obtained in the current study. Map unit 31 occupies 4250 ha within the region (NPWS 2000). Combined with the other two minor communities, a conservative estimate of approximately 40120 ha of potential *Angophora inopina* habitat remains in the region, yet only 1655 is protected within formal conservation reserves within the lower Hunter Valley and Central Coast (NPWS 2000).

Extensive areas of coppicing and the mallee habit in *Angophora inopina* may well be a relatively recent response to environmental change. Increased fire frequencies from arson and prescribed burns since European settlement have evidently initiated regular lignotuberous regrowth in some areas, perhaps at the expense of seedling recruitment. For the rare tree *Eucalyptus squamosa*, Dove (1984) and Raine (1990) found that low present- day recruitment, and the presence of mallee forms in most stands, suggested that populations in the Central Coast area are responding to some form of environmental stress. Raine (1990) suggested that energy expenditure toward sexual reproduction was superceded by the need to survive in an adverse environment, as evidenced in low seed production and vegetative (mallee) growth. For the threatened *Eucalyptus camfieldii*, Prober (1985) found that the habitat of this species was typical of that found on Hawkesbury Sandstone ridges within the Sydney region, and was not considered sufficiently unusual to explain its rarity. In contrast to *Eucalyptus squamosa*, fruit and seed production was found to be abundant, with germination occurring between eight and thirty days after sowing. Field observations undertaken by Prober (1985) revealed a general lack of seedlings within *Eucalyptus camfieldii* stands, supporting the earlier notion of Matt and Groves (1980) that mallee eucalypts rarely establish successfully from seed. Davies and Myerscough (1991) also found a similar result with the rare mallee *Eucalyptus luehmanniana* near Sydney, a species which undergoes a mass release of seed following fire events. Prober (1985) pointed towards subtle competitive factors or broad climatic variations (rather than restriction to a scarce habitat) to help explain the rarity of *Eucalyptus camfieldii*. Observations to date on *Angophora inopina* would suggest similar causes of rarity in this species; the work of Tierney (2004) would support this.

Conservation status and management implications

Angophora inopina is known from the Central Coast, and from Port Stephens and Great Lakes LGA's on the mid North Coast of New South Wales. Populations within the Central Coast are disjunct from those on the mid North Coast, separated by the Hunter River estuary and the extensive agricultural and urban landscapes in the lower Hunter Valley. Management of the species should ideally be organised separately for populations on the Central Coast, and on the mid North Coast. A conservation strategy has been drafted by Wyong Shire Council for the southern populations, which incorporates habitat quality·information, and employs various conservation criteria to assist in the prioritisation of occupied habitat. A similar strategy is required for the mid-North Coast, where continuing developments are threatening existing habitat.

Small populations occur within Lake Macquarie State Conservation Area, Karuah Nature Reserve and Wallaroo Nature Reserve (Bell 1998, Bell 2001b, Leonard 2001). None of these reserves support more than 1000 plants (unpubl. data) and it is evident that off-park conservation of the species will be required in the long term. On the Central Coast, though a small population exists within Lake Macquarie State Conservation Area, all other occurrences are on Crown or private land. Evidently, a landscape scale approach to conservation of the species is required; on the Central Coast this process would also allow protection of other threatened plant species which occupy similar habitats (e.g. *Cryptostylis hunteriana*, Bell 2001c, *Acacia bynoeana* & *Tetratheca juncea*, pers. obs.).

Management issues for *Angophora inopina* populations on the Central Coast include fire frequency and intensity, rubbish dumping, weed invasion, indiscriminate off-road recreational driving on Crown lands, introgressive hybridisation with *Angophora floribunda* [as is apparent for the threatened *Angophora exul* (Hill 1997); see Potts et al. 2003 for discussion on the risks of hybridisation], and urban and agricultural expansion. As Tierney (2004) has indicated, fire frequency is in itself a significant environmental variable for this species. He suggests that fire-free periods of at least 15 years are required for seedlings to attain maturity and commence flowering and seed production (although fire-tolerance may be attained at around 7 years, subsequent to which individuals may survive repeated fire). As individual *Angophora inopina* specimens are long-lived, such a fire-free window may only need to occur infrequently for successful recruitment to the population to occur. Many other rare plant species are similarly threatened by inappropriate fire regimes in the wider region (e.g. Auld et al. 1993, Bradstock et al. 1995, Keith 1996).

Anecdotal evidence suggests that invasion by weed species, particularly exotic grasses, may be impacting on the germination of *Angophora inopina* seedlings, and this threat is perhaps the most urgent. Considerable areas of occupied habitat occur within highly fragmented urban and rural-residential land tenures, and area-to-edge ratios are high. In several Central Coast sites with an understorey of invasive grasses (e.g. *Axonopus affinis*), flowering and fruiting of *Angophora inopina* has occurred but very little seedling recruitment is evident (D. Tierney pers. comm.). Studies on threatened and other plants illustrate the threats to germination and establishment posed by exotic species (e.g. Vranjic et al. 2000, Standish et al. 2001), and the process is also listed as a Key Threatening Process on the NSW *Threatened Species Conservation Act 1995*.

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Bryophyte composition in a native grassland community subjected to different long-term fire regimes

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Abstract: The vascular species composition of volcanic plains grassland remnants of western Victoria is strongly tied to management history, with frequently burned remnants often supporting the most diverse native flora relative to grazed and long-unburned remnants. How the fire regime affects the composition of the bryophytic mat, however, has not been documented. I surveyed the moss and liverwort flora of six *Themeda triandra* grasslands subjected to different long-term fire regimes to understand how fire might affect mat composition. A total of 27 non-vascular species (19 mosses and 8 liverworts) were recorded, of which nine species were recorded only from a single location. Non-vascular species contributed 28% of the total diversity observed in this study. The liverwort *Lethocolea pansa* was the most obvious species at all sites, while the mosses *Rosulabryum billardieri* and *Fossombronia intestinalis* were also found at all sites and hence, would appear to be robust to fire at different frequencies. Frequently-burned (1–2 yr interval) grasslands generally had lower mat species richness than longer-unburned sites (4 to >20 yr intervals) and appear to support a subset of the flora (due to the loss of moss species) rather than a distinctly different flora. The preliminary results of this study contrast with the evidence usually found for vascular species, i.e. that frequent fire favours greater native species richness. Hence, the two components of the flora would appear to respond in different ways to fire and this should be considered in the conservation planning for this grassland community. Further field sampling is warranted to confirm the initial trends identified by this study.

***Cunninghamia* (2004) 8(4): 485–489**

Introduction

Remnant native grasslands on the western volcanic plains, Victoria persist in small areas such as railway verges and cemeteries where domestic stock have been excluded over the last 120 years.These sites have been frequently burned, not for conservation purposes, but to reduce the threat of wildfire to rural communities (McDougall et al. 1994). The effects of these fire regimes are well known for many plant species (e.g. Stuwe & Parsons 1977, Lunt & Morgan 2002). Frequent fire (e.g. 1–3 year intervals) maintains a species-rich grassland community by mediating the competitive effects of the dominant grass, *Themeda triandra* (Stuwe & Parsons 1977). As time-since-fire increases, the native flora generally becomes depauperate, not successionally different or diverse, i.e. it often represents only a subset of the species that would normally be present in frequently burnt sites (Stuwe & Parsons 1977).

A substantial and largely neglected component of temperate grasslands is the non-vascular species — the mosses and liverworts (= bryophytes), lichens, cyanobacteria, fungi and algae — that carpet the intertussock spaces in a complex mosaic to form a biological soil crust. Scarlett (1994) gives a general account of the biological soil crust of railway reserve *Themeda triandra* grassland remnants in western Victoria, showing that they are dominated by bryophytes rather than lichens and hence, the crust should be more correctly termed a bryophytic mat. Few studies have thoroughly documented the composition of the non-vascular component of grasslands at any site on the volcanic plains in Victoria, and only Morgan and Rollason (1995), who list 32 species for a remnant grassland near Sunbury (comprising 22 mosses and 10 liverworts), have published a non-vascular species list to complement the more usual vascular species list.

The common practice of overlooking non-vascular species in botanical surveys due to their small size and (perceived) difficulties in identification fails to recognise their (a) contribution to local diversity and (b) important ecological role in ecosystems (Eldridge et al. 2003). Including mat species in the species list of a remnant urban grassland in Melbourne, Victoria, for example, increased the known diversity of that remnant by 25% (Morgan & Rollason 1995). Ecologically, biological soil crusts are known to contribute significantly to carbon and nitrogen fixation and soil stabilisation (McKenna-Neuman et al. 1996, Leys & Eldridge 1998), particularly in semi-arid ecosystems, and can both positively and negatively affect germination of native and exotic species in semi-arid and temperate communities (Zamfir 2000, Otsus & Zobel 2004). Biological soil crusts in semi-arid areas are also important indicators of site degradation, often taking long periods (e.g. several decades) to recover after soil disturbance (Belnap 2003).

How non-vascular species have responded to the different fire regimes imposed on volcanic plains grassland remnants of western Victoria over the last century is unknown. All work on the effects of fire on biological soil crusts in eastern Australia has previously been conducted in semi-arid

Table 1. Location of the study sites in western Victoria, their description and long-term burning history.

Site name	Location	Land tenure; size of remnant	Soil features	Annual rainfall (mm)	Alt. (m)	Burning history
Chatsworth Rd (CR)	37°51'S, 143°05'E	Roadside verge; 15 ha	Brown to red-brown clay, pH 6.8	620	195	Burnt annually in late summer since 1950
Victoria Point Rd (VPR)	37°36'S, 142°09'E	Roadside verge; 6 ha	Dark brown clay, pH 6.5	700	250	Burnt every 1–2 yrs in summer for possibly >50 yrs
Doyles Rd (DR)	38º 04'S, 143º 51'E	Roadside verge; 1.5 ha	Dark brown clay; pH 6.5	620	180	Burnt at 1–2 yr intervals in early summer for decades.
Bannockburn (B)	38°02'S, 144°09'E	Railway verge; 3 ha	Brown to red-brown clay; pH 7.1	610	120	Burnt approx. every 3–4 years for last 15-20 yrs
Brewis Rd (BR)	37° 37'S, 142°12'E	Roadside verge; 6 ha	Dark brown to grey clay or clay loam; pH 6.8	700	230	Unburnt for probably much longer than 20 yrs
Rankins Rd (RR)	37°36'S, 143°26'E	Roadside verge; 2 ha	Dark brown clay to clay loam; pH 6.7	630	290	Unburnt for at least 15–20 yrs, probably much longer

ecosystems on sandy soils. Greene et al. (1990) found that annual burning for seven years in a semi-arid woodland completely destroyed the cryptogamic layer, whilst Eldridge and Bradstock (1994) found that frequent fire maintained cryptogamic cover at low levels in a eucalypt shrubland. Are similar effects also occurring in a temperate plant community on clay-rich soils that is likely to have experienced very frequent fire? The aim of this study was to document the composition of the bryophytic mat (specifically the mosses and liverworts) of six native grassland sites that had been subjected to different long-term fire regimes.

Methods

Study sites

The study was conducted on the flat to undulating treeless volcanic plains of western Victoria. The soils are red-brown to grey acidic cracking-clay loams to clays of variable depth on Quaternary basalt (Stuwe & Parsons 1977). The climate is temperate with cool winters (mean minimum temperature of the coldest month (July) is approximately 4°C) and warm summers (mean maximum temperature of the warmest month (January) is approximately 26°C) (Bureau of Meteorology & Walsh 1993). Rainfall is evenly distributed throughout the year, with a slight peak in spring (September), but summer drought is common. A rainfall gradient exists from west (high) to east (low) across the plain.

A tussock grassland community dominated by *Themeda triandra* (Kangaroo Grass) naturally occupied approximately half of the 21 000 km^2 volcanic plain (McDougall et al. 1994). Species from the Asteraceae, Fabaceae, Cyperaceae and Liliaceae are common in the intertussock spaces.

Since European settlement, much of the volcanic plains landscape has been converted to agriculture and remnants of the original vegetation have been reduced to tiny fragments where stock grazing and pasture improvement have been minimal or absent (McDougall et al. 1994). Disturbance has usually been restricted to frequent burning (i.e. 1–3 yr intervals) in summer by rural fire brigades to reduce the chance of wildfire to local communities (McDougall et al. 1994). Along railway lines, the railway verge was usually burnt, almost annually, in late-spring and early summer to prevent fires igniting from passing steam trains (Stuwe & Parsons 1977).

Floristic composition of sites with different fire histories

The chronosequence method was used to document change in biological soil crust composition with different fire regimes. This method assumes that the grassland sites studied were floristically similar across their range before different management strategies were imposed decades ago. The approach also assumes that the site floras which have subsequently developed are a consequence of the management regime, although chance events, climatic and soil variation undoubtedly also play a major role (McDougall et al. 1994). Caution is therefore warranted when interpreting the effects of fire history on biological soil crust composition, although some of this uncertainty can be reduced by replicating the observations of the management regimes under study by including multiple sites that have been subjected to these 'treatments'.

Six native grasslands dominated by *Themeda triandra* were selected to encompass the range of burning management regimes in the area (i.e. infrequent (i.e. >15 yrs) burning for extended periods (2 sites), annual (3 sites) or 4-yr interval (1 site) fire frequencies that have been perpetuated for decades) (Table 1). Sites were selected on the basis that their management history was well known, that exogenous soil disturbance was minimal and that the vegetation was dominated by native species. Management history was obtained from published and unpublished literature, and from discussions with local fire brigade members.

In August 1998, a single 150 m^2 quadrat was randomly located at each site in visually homogenous vegetation to characterise the non-vascular and vascular species composition. The sites were surveyed using a timed meander search (60 minutes). Moss and liverwort species were

Table 2. Biological soil crust composition of native grassland sites subjected to different long-term fire histories. See Table 1 for explanation of site codes and burning history.

Abundance was estimated in each 150 m² quadrat: + = present as few traces or small colonies; 1 = becoming conspicuous but with low cover; 2 = a prominent feature and cover obvious.

	Sites					
Species	**CR**	**VPR**	**DR**	**B**	**BR**	**RR**
Mosses						
Archidium stellatum	1			1		1
Barbula crinita			1	1	1	1
Bartramia ithyphylla				1		1
Bartramia stricta			2	1		
Breutelia affinis					2	
Bryum dichotomum	1	1	1	1	1	
Campylopus clavatus		1		1	1	1
Fissidens sp.	1			1		1
Fissidens megalotis		1				
Fissidens taylorii	1			1		1
Fissidens tenellus		1				
Gigaspermum repens				+		
Hypnum cupressiforme					2	
Philonotis tenuis		1	1			1
Pleuridium nervosum				1		
Polytrichum juniperinum						1
Rosulabryum billardieri	1	1	1	1	1	1
Totula atrovirens					1	
Triquetrella papillata					1	1
Liverworts						
Anthoceros sp.	1	1				1
Asterella drummondii					1	1
Cephaloziella exiliflora			1			
Chiloscyphus semiteres				1	1	1
Fossombronia intestinalis	1	1	1	1	1	1
Fossombronia sp.	1	1				1
Lethocolea pansa	2	2	2	2	2	2
Riccia bifurca	1	1		1		1
Total No. of Mosses	5	5	6	11	8	10
Total No. of Liverworts	5	5	3	4	4	7
Total Species Richness	**10**	**10**	**9**	**15**	**12**	**17**

searched for between tussocks and on any outcropping rock present. They were then recorded and collected and assigned a nominal abundance value using Watson (1960) as a guide, to illustrate their relative importance (Table 2). Fungi and algae were regrettably ignored while lichens were uncommon. All vascular species present were also recorded and the percent cover of the dominant grass, *Themeda triandra*, was estimated in ten 1 m² quadrats haphazardly placed throughout the larger quadrat. Non-vascular species were identified in the laboratory using a dissecting microscope and voucher specimens retained. Mosses and liverworts were identified using the keys of Scott and Stone (1977) and Catcheside (1980) while nomenclature follows Meagher and Fuhrer (2003).

The relationship between vascular species richness and non-vascular species richness was examined by Spearman rank correlation (Quinn & Keough 2002), as was the relationship between non-vascular richness and mean percent cover of *Themeda triandra*.

Results

A total of 27 bryophytes (Table 2) and 69 vascular species were recorded at the six sites with mosses more common (19 species in total) than liverworts (eight species in total). Hence, non-vascular species contributed 28% of the diversity observed in this study. Bryophytic mat species richness was low at all sites (9–17 species per quadrat) and lower in sites burnt annually (mean 9.7 species per quadrat) than sites burnt at 4–20 year intervals (mean 14.7 species per quadrat). The liverwort *Lethocolea pansa* was found at every site and was also the most conspicuous non-vascular species (by cover) at all sites. The mosses *Rosulsabryum billardieri* and *Fossombronia intestinalis* were also found in all grasslands. Nine soil mat species, eight of which were mosses, were recorded from a single site (Table 2). Fifty percent of these 'singleton' mosses were found in the two unburnt sites. Frequently burnt sites appear to support a subset of the longer-unburnt non-vascular flora rather than a distinctly different flora (Table 2). This simplification results mostly from losses in mosses with increasing frequency of fire (Table 2). The liverwort *Chiloscyphus semiteres* was also conspicuously absent from sites burnt more frequently than every 3–4 years (Table 2).

No significant correlation was found between non-vascular and total vascular species richness (r = 0.055, p = 0.913). Non-vascular species richness was strongly associated, however, with mean percent cover of *Themeda triandra* (r = 0.925, p = 0.008, Fig. 1).

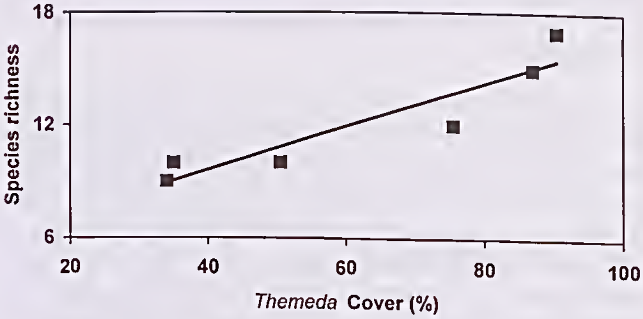

Fig. 1. Relationship between the cover (%) of the dominant grass (*Themeda triandra*) and the number of bryophytic mat species sampled from six grasslands in western Victoria.

Discussion

This preliminary study suggests that frequent fire may reduce the number of mat-forming species (specifically mosses) found in the intertussock spaces of *Themeda*-dominated grasslands on the volcanic plains of western Victoria. Moss richness was higher in longer unburned areas, suggesting that mosses do not survive repeated fire at short return intervals. This may be due to the effects of fire *per se* consuming plants or the post-fire environment which may be much drier. By contrast, liverworts were found at all sites, often at high cover, suggesting a greater resilience to fire.

The exception was *Chiloscyphus semiteres;* this species was absent from annually burnt sites but found elsewhere. The preliminary data therefore suggest that differences in bryophytic mats after fire are mostly the result of the slow recovery of the mosses as has been found in other ecosystems (Johansen et al. 1984). Management practices would therefore appear to be potentially important influences on mat composition in grasslands as they may impact on recolonization patterns. Changes in fire regimes are likely to have the most effect on the non-vascular flora and should be considered in conservation planning. In particular, sites that go from being infrequently- to frequently-burnt may lose aspects of the moss and liverwort flora (Greene et al. 1990, Hilty et al. 2004). Detailed surveying of the biological soil crust at a range of temperate grassland sites with different fire frequencies is necessary to determine whether these initial trends are supported. An important analogous question is whether grassland sites currently experiencing high fire frequencies can recover bryophtic mats with a reduction in their fire frequency. This is completely unknown and worthy of future study.

The effects of fire on bryophytic mat diversity reported here, however, have some similarity with the findings of studies conducted on biological soil crusts in semi-arid rangelands. Eldridge and Bradstock (1994) found that moss cover declined after annual fire on aeolian sands and that their recovery may take many years, if not decades. Where fire is very frequent, only algae were present. Similarly, Johansen et al. (1984) report the slow recovery of mosses after fire in desert rangelands in Utah, USA, such that five years after fire, recovery was not complete either in terms of biomass or composition.

Some differences in the response to fire of temperate grassland soil mats relative to semi-arid biological crusts, however, are also obvious. While single fire events have been reported to reduce the abundance of liverworts in some habitats (e.g. Florida rosemary scrub (Menges & Kohfeldt 1995) and desert rangelands (Johansen et al. 1984)), liverworts were common at all sites in the present study regardless of fire frequency. *Lethocolea pansa* was one of the conspicuous and dominant species at all sites, suggesting that responses of bryophytic mats to fire may be species-specific. Additionally, frequent fire has probably been a feature of temperate grasslands in south-eastern Australia for centuries (Lunt & Morgan 2002) and hence, fire-sensitive crust species are likely to have been eliminated there long ago unlike many of the less frequently burnt semi-arid communities where much of the biological crust research has been conducted (Eldridge 2003).

No simple linear relationship was observed between vascular and non-vascular species richness in this study. Species-rich grasslands in southern Victoria generally occur in areas ungrazed by stock where fire is sufficiently frequent (i.e. 1–3 yr intervals) to prevent competitive exclusion (for space, light, water, nutrients) by the dominant tussock grasses (Lunt & Morgan 2002). By contrast, the richest bryophytic mats observed in the present study occurred where fire was less frequent and hence, sufficient time elapsed between fire events for the slow recolonisation of species and/or development of microsite conditions conducive to bryophytes. These areas often support lower vascular species richness. Dominant grass (*Themeda*) cover is highest in the longer unburned sites and this canopy cover may provide shade and protection from desiccation for many non-vascular species such as *Triquetrella papillata* (Eldridge et al. 2000), although deep shading and litter deposition for extended periods can reduce their cover (Scarlett 1994). Interestingly, biological crust cover also declines in long unburned mallee shrublands due to increases in litter (Eldridge & Bradstock 1994) and in ungrazed disclimax native grassland (Eldridge et al. 2000).

The vascular and non-vascular flora of the temperate grasslands in the present study recover from fire at considerably different timescales. While frequent fire favours vascular species richness due to resprouting of the bud and tuber bank (Lunt & Morgan 2002), such fire regimes do not enable maximal species diversity of bryophytic mat species to develop. This difference should be given some consideration when conservation planning for temperate grasslands is undertaken. Clearly, it will be almost impossible to maximize both vascular and non-vascular species richness using a single fire regime. A range of fire regimes is warranted across the range of grassland remnants that persist to conserve the greatest range of vascular and non-vascular flora. Using a range of fire regimes across the landscape has been acknowledged as important for vascular species conservation (Scarlett & Parsons 1982). However, non-annual fire regimes are necessary to promote rare legumes and some shrub species and it appears that non-vascular species richness will also benefit greatly by maintaining longer fire-free intervals. The complete absence of fire (or disturbance *per se*), however, is likely to lead to declines in richness of both non-vascular (Eldridge et al. 2000) and vascular species (Stuwe & Parsons 1977). While the findings presented here should be considered preliminary, it appears that greater attention to bryophytic mat diversity, ecology and function is warranted in native temperate grasslands.

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Conservation issues for the vascular flora of Lord Howe Island

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Abstract: The flora of the Lord Howe Island Group (31°30'S, 159°05'E) comprises a unique mix of elements of Australian, New Zealand and New Caledonian floras. It is significant for its high degree of endemism and for its structural and biological (leaves, flowers, fruit) role in supporting a diverse array of fauna. Conservation of this flora is dependant upon: reducing current habitat degradation (mostly the result of exotic weeds); minimising any future impacts, in particular the effects of climate change on the unique cloud forests of the southern mountains and the continued introduction and spread of weeds and the pathogen *Phytophthora cinnamomi*.

We provide a description of the nature of the major threats to the flora and suggest an area-based scheme, focussed on the relative conservation significance of remaining vegetation, as a mechanism for developing priorities for threat mitigation activities. While a number of threat control works are in place, eg. weed control, some re-emphasis is needed. In addition, some new initiatives are required including: reducing the rate of introductions of new exotics; a system to remove potential environmental weeds from the settlement area; phytosanitary guidelines; pathogen quarantine measures; search and removal of environmental weeds from remote areas; and *ex situ* initiatives for plant species restricted to the cloud forests of the southern mountains.

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Introduction

Lord Howe Island (31°30'S, 159°05'E) is a small oceanic island some 570 km from the east of Australia, 1350 km from New Zealand and 1250 km from New Caledonia. The Lord Howe Island Group consists of the main Lord Howe Island (11 km long and between 0.6 and 2.8 km wide, with a land area of 1455 ha) and a number of small surrounding islands (including Admirality Islands, Blackburn (or Rabbit) Island, Mutton Bird Island, Gower Isalnd and Balls Pyramid). The flora of the island has high conservation significance for a range of reasons. The flora represents a unique mixture of Australian, New Zealand and New Caledonian floral elements (Oliver 1917, Pickard 1983a, Green 1994), the combination of which is extremely rare in the world. Although other Pacific Islands such as Norfolk Island and the Kermadec Islands also have these three floral elements (Mueller-Dombois & Fosberg 1998), each of these island groups has a unique flora. On the basis of floristic affinity, van Balgooy (1971) considers Lord Howe Island to represent a floristic district within the New Zealand sub region, based on the distinctiveness of the genera shared with New Zealand and the absence of the most characteristically Australian genera such as *Eucalyptus, Acacia* and those from the Proteaceae. However, as most plant affinities with mainland Australia are for rainforest elements, the lack of dry forest Australian genera is not too surprising. Australia and Lord Howe Island have never been connected and the entire flora is considered to be long-distance dispersed. Submerged seamounts in the Tasman Sea indicate the former existence of other islands that have probably facilitated migration of plants and animals between Lord Howe Island, Australia and New Caledonia. A suite of plants exist on Lord Howe Island that have been transported by wind, birds or ocean currents along these former stepping stone islands.

The flora of Lord Howe Island has a high level of endemism and many of the floristic assemblages are also unique to the island group (Pickard 1983a, Green 1994). There are five plant genera endemic to Lord Howe Island — *Negria, Lordhowea* and three palm genera *Howea, Hedyscepe* and *Lepidorrachis.* For the vascular plants, Green (1994) lists 459 species, 241 indigenous (53%), of which 105 are endemic (44%) and 218 naturalised (48%). Of the indigenous vascular plants, 58 species are ferns and 183 are flowering plants. Several more species of both indigenous and naturalised plants have been found since Green's (1994) work. The high level of endemism is typical of islands and comparable with megadiverse regional areas of continents (Lowry 1998). Of the 241 indigenous vascular plant species on Lord Howe Island, 129 are also found in Australia, 102 are also found in New Caledonia, 75 also occur in New Zealand and 66 also occur on Norfolk Island. The only genus confined to Lord Howe Island and Australia is *Westringia*, the only genus confined to Lord Howe Island and New Zealand is *Carmichaelia.* Lord Howe also has many plant genera that occur more widely across the Pacific islands, such as *Alyxia, Dracophyllum, Elaeocarpus, Elaeodendron, Melicope, Metrosideros, Ochrosia, Pisonia, Psychotria, Sophora* and *Xylosma*. The floristic structural and biological (e.g. leaves, flowers, fruits) components of the flora are important as habitat structure and resources for the unique Lord Howe Island fauna (Cassis et al. 2003).

Less detailed information is available on the non-vascular flora. The mosses of Lord Howe Island are diverse and show great affinity with the mosses of Australia and New Zealand. Ramsay (1984) listed 105 moss species from 36 families, with 21% endemic species for Lord Howe Island. 102 species of lichens are listed for Lord Howe Island (Elix & McCarthy 1998) with a number of endemics. For example, Archer and Elix (1994) studied the lichen genus *Pertusia* on Lord Howe Island and listed 20 species, 5 of them endemic.

Although there has been extensive clearing for settlement of the lowland area of the main island on the Lord Howe Island Group, much of the northern hills and southern mountains remains intact and protected within a Permanent Park Preserve. This represents some 80% of the main island (Davey 1986). A number of major threats currently affect the survival and reproduction of the flora and the interactions that occur between plant and animals species. Management of these threats requires an understanding of: (i) the conservation status of the various species, populations and ecological communities and their distribution across the landforms of the island; (ii) the dynamics of component species and communities; and (iii) the nature and potential impact of threats. Whilst Pickard (1983b) assessed the conservation status of vascular plant species on Lord Howe Island, our understanding of the other issues is somewhat limited. Because of the different soil types and landform features, the vegetation varies across the island. When combined with the history of clearing for the settlement area (generally in the low lying areas), the remnant vegetation and associated species of conservation significance are not evenly distributed across the island and associated islets. This variation influences the practicalities of how to best deal with the conservation of the flora for land managers. Lord Howe Island is a part of New South Wales and both state (NSW *Threatened Species Conservation Act* 1995) and Federal (*Environment Protection and Biodiversity Act* 1999) threatened species legislation applies to the island.

Landforms and climate

The Lord Howe Island Group is considered to be the eroded remnant of a large shield volcano, approximately 7 million years old. Together Lord Howe Island and Balls Pyramid are the emergent portions, on two adjacent summits, of a large, nearly truncated, seamount. The water surrounding Lord Howe Island and in the Tasman Sea generally is between 1000 and 4000 metres deep.

The original Lord Howe Island would have been approximately 30 km in diameter, and 1,000 metres above current sea level in height. Today the island is 11 km long and 2.5 km at its widest point and a height of 875 metres above sea level. Balls Pyramid is a rocky island 23 km south-east of Lord Howe Island, with its base 1 km long and about 200 m wide. The volcanic rocks of both islands are typical mid-oceanic hot spot lava flows interspersed with tuff layers.

In more recent geological history, sedimentary calcarenite has been deposited on the low lying areas of the island as old lagoon floor, beach and sand dune deposits. The grains of sand in this calcarenite are calcium carbonate, derived from marine organisms such as corals, molluscs and foraminifera living in the surrounding shallow waters that existed as large shelf areas in periods of lower sea levels over the past 120,000 years.

The climate of Lord Howe Island is humid-subtropical. It has a mean annual temperature of 19.2°C, ranging from 25°C –17°C in summer to 18°C–14°C in winter (Mueller-Dombois & Fosberg 1998). Average annual rainfall is 1717 mm, with a maximum of 2886 mm and a minimum of 998 mm (Mueller-Dombois & Fosberg 1998). Rainfall is unevenly distributed throughout the year, with an average low of 100 mm in February and a high of 200 mm in June/July. Generally the rainfall is in the form of short duration, moderate to heavy showers and thunderstorms rather than slow steady rain. Relative humidity is consistently moderate, at 75–78%. Strong winds are characteristic, with westerlies dominating in winter and easterlies in summer (Hutton 1986).

Major threats to the vascular flora

Weeds

The vegetation of Lord Howe Island has been severely affected by introduced plants and over 241 plant species have become naturalised (Pickard 1984, Green 1994, Hutton & Le Cussan 2001). A number of these are having a serious impact on the persistence of individual native species and the structure of ecological communities. Pickard (1984) demonstrated that the arrival of exotic plants onto Lord Howe Island had occurred at an exponential rate from 1853–1981. Data from Hutton and Le Cussan (2001) on current weed species on Lord Howe Island and exotics arriving since 1980 match the expected number of exotics based on an exponential rate of increase (Pickard 1984). This implies that there has been no slowing of the rate of introductions of exotics in the past 20 years and that new introductions are continuing e.g. the legume *Macroptilium atropurpureum* (Siratro) was first recorded on Lord Howe Island in 2002. This demonstrates a significant failure in weed control for the island as future weed impacts will be dependant on both the magnitude and type of weeds that are brought to Lord Howe Island. Simberloff (2000) suggests two key outcomes that would significantly improve the conservation of island floras: 1) less habitat loss (currently occurring on Lord Howe Island, see below); and 2) a decline in the rate of introductions of non indigenous species (not occurring at present).

On Lord Howe Island, 17 introduced species are listed as Noxious weeds under the NSW *Noxious Weeds Act 1983*, and a further 36 species may be considered environmental weeds that are either slowly becoming established in the natural vegetation, or are weedy elsewhere and should be removed. Weeds of particular concern at present are *Psidium cattleianum, Pittosporum undulatum, Chrysanthemoides monilifera, Ageratina adenophora, Asparagus aethiopicum, Asparagus plumosus* and *Lilium formosanum.*

Psidium cattleianum is a serious woody weed of subtropical island ecosystems in the world (Lowe et al. 2000). It is the major woody weed on the Galapagos Islands, Mauritius, Seychelles, Hawaii, Norfolk Island, and Lord Howe Island. More urgent attention to eradication/control of this plant on Lord Howe Island is needed. At the same time, the relative impact of some weeds has changed over the last 30 years. For example, Pickard and Clark (1974) suggested that the *Asparagus* spp. were rare in undisturbed vegetation and that there was doubt as to the 'seriousness of these plants'. Currently, these weeds collectively represent one of the most significant threats to the vegetation of Lord Howe Island. *Pittosporum undulatum* was introduced in 1898 and has spread slowly into undisturbed forest (Pickard 1984). Since 1984, it has continued to spread southward and has now reached Intermediate Hill (Hutton & Le Cussan 2001). Pickard (1984) warned of the potential spread of several weeds. This warning has not been heeded and several weeds that were brought to Lord Howe Island in the 1970–1980s are now becoming serious environmental weeds. For example, *Ochna serrulata* was introduced as an ornamental in 1980 (Pickard 1984) and has now spread to the north face of Mount Lidgbird in the southern mountains (Hutton & Le Cussan 2001).

The Lord Howe Island Board has an extensive weed control program (Lord Howe Island Board 2002b). This is combined with volunteer weeding programs. The current program is targeted, but may need some refinement to better focus on restricting the spread of serious weeds in the highest priority area (the southern mountains and Intermediate Hill) e.g. *Psidium cattleianum* and *Asparagus* spp. (see below).

Loss and degradation of habitat.

Most of the loss of vegetation has occurred in the settlement area and little further habitat loss is expected for urban development. About 15% of the island forest has been cleared for housing, gardens or grazing. Most of this is lowland forest of the type *Cryptocarya triplinervis/Drypetes deplanchei* closed forest (Pickard 1983a). This forest type is one of the habitats for two endangered animals (the Woodhen *Tricholimnas sylvestris* and the land snail *Placostylus bivaricosus*).

The impact of this clearing has gone beyond the removal of individual trees and understorey. The majority of the forest of the island is rainforest and when the natural border of hardy small trees and shrubs is removed the exposed trees are affected by the strong, salt laden winds that blow across the island, particularly during winter months (Pickard 1983a). The exposed trees gradually lose their leaves and may die over a period of some decades. This dieback has been noted by botanists before 1900 (Pickard 1983a). This dieback is exacerbated by the invasion into the forest by the pasture grasses *Pennisetum clandestinum* (Kikuyu) and *Stenotaphrum secundatum* (Buffalo) which grow over native trees and shrubs trying to establish on the forest edge. The Lord Howe Island board has developed a revegetation program (Lord Howe Island Board 2002a) to attempt some habitat restoration in areas affected by tree dieback due to exposure.

Impacts of exotic animals

There have been a number of introductions of animals to Lord Howe Island. Pigs and goats had locally significant impacts (Pickard 1976). Pigs were eradicated in 1979 and goats have been virtually eliminated from the island. Currently, the most serious exotic animals are likely to be rats and mice. These may consume fruits, seeds or vegetative material and hence limit reproduction, recruitment of new plants and plant vigour and competitive ability, but very little is known about their impact. Further study is required on those species that have been observed to suffer heavy predation e.g. loss of fruits and seeds (*Baloghia inophylla, Chionanthus quadristamineus, Drypetes deplanchei, Elaeodendron curtipendulum, Pandanus forsteri, Ochrosia elliptica*); loss of seedlings and stem damage (the four palm species, *Hedyscape canterburyana, Howea forsteriana, Howea belmoreana, Lepidorrhachis mooreana, Dietes robinsoniana* (Wedding Lily) and at least two fern species, *Asplenium milnei* and *Adiantum hispidulum*). The extinctions of two Lord Howe Island plant species, *Sicyos australis* and *Solanum bauerianum*, were most likely influenced by consumption of seeds and fruits by introduced animals.

There is the potential for rat and possibly mouse control on Lord Howe Island (Saunders & Brown 2001) but no assessment of the impact of rodents on the flora is currently available to inform control methodologies or to prioritize areas for control if eradication is not possible or not successful. This needs to be addressed in the lead up to the development of any rodent control strategy.

Two other threats have the potential to have a major impact on the flora, and preventative actions need to be taken to reduce potential impacts. These threats are:

Climate change

The summits and upper slopes of the southern mountains on Lord Howe Island contain unique assemblages of plants and animals, in particular in association with cloud forest vegetation. This vegetation is most extensive on the summit of Mount Gower (875 m) (Pickard 1983a). Moist air flowing across the summit is forced to rise, and the condensation results in semi permanent cloud shrouding the summits, particularly during the summer months. The resulting high humidity provides conditions for many unique species to exist. The cloud forest consists of dwarf rainforest trees about 5 metres high, with an abundance of mosses, ferns and liverworts covering the ground, tree trunks, branches and rocks. Approximately 86% of plant species on the summit are endemic.

One of the predictions arising from modelling the impacts of climate change is that there is likely to be upward altitudinal shifts in the areas that receive cloud formations (Still et al. 1999). If this prediction holds for Lord Howe Island, then there may be reduced formation of clouds on the southern mountains and reduced precipitation. This is likely to have negative impacts for species occupying both the cloud forests themselves and the associated mountain slopes.

At present, there are no active actions in relation to possible impacts of climate change on Lord Howe Island. At a minimum, investigations should be made into propagation and *ex situ* storage techniques for species restricted to the cloud forests (Harris et al. in press). This may include both seed banking and/or living collections.

Exotic pathogens

Exotic pathogens can drastically alter the vegetation composition and structure in habitats that are sensitive to these pathogens. In Australia, the exotic pathogen *Phytophthora cinnamomi* is widespread and has been shown to severely impact on certain species or plant communities across a range of environmental regions (Environment Australia 2001). This pathogen was recently identified as present on Lord Howe Island in 2003, where it was identified in a small orchard on cleared land at the southern end of the settlement area (B. Summerell pers. comm.). Unidentified species of *Phytophthora* were also found at several lowland sites in the settlement area. There are a number of plant taxa on Lord Howe Island that are closely related to taxa that have been severely impacted by *Phytophthora cinnamomi* in other parts of the world (Table 3). Such species are potentially susceptible to this pathogen; urgent action is required to quarantine the known infected area, carry out detailed surveys for the presence of *Phytophthora cinnamomi* around drainage lines in the known location and to test susceptibility of the species listed in Table 3. In addition, a set of phytosanitary guidelines is urgently needed to avoid any further importations of this pathogen and to prevent its spread to forested parts of Lord Howe Island.

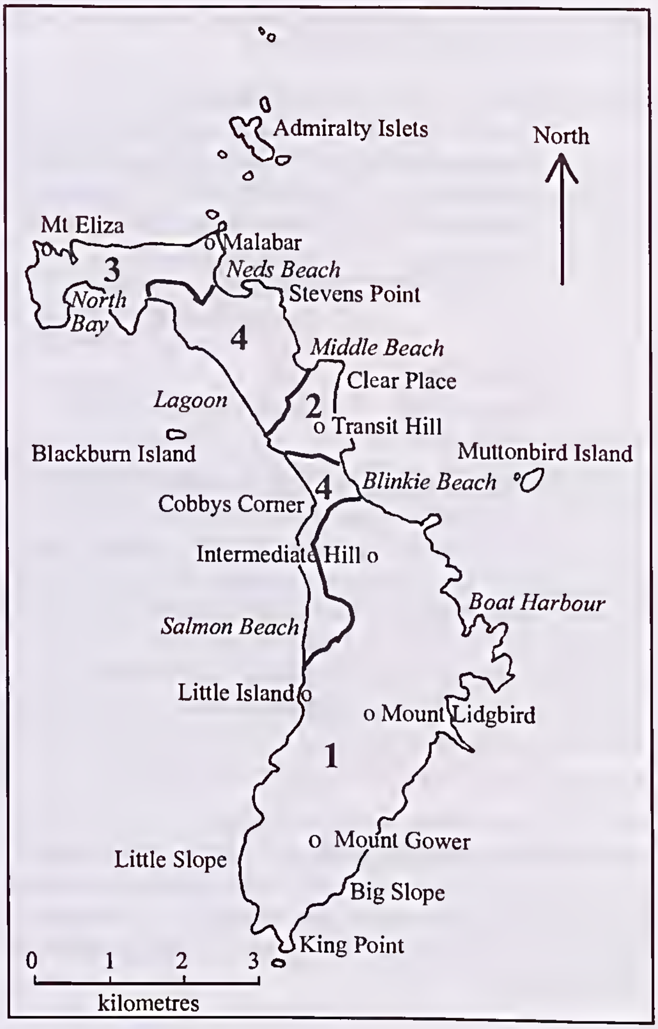

Fig. 1. Proposed Conservation Management Zones for Lord Howe Island

Group

1 Southern Mountains and Intermediate Hill
2 Transit Hill
3 Northern Hills
4 Settlement Area
5 Coastal dunes (including Neds Beach, North Bay, Lagoon Beach, Middle Beach, Blinky Beach, Salmon Beach)
6 Offshore Islets (including Admirality Islands, Blackburn (or Rabbit) Island, Gower Island, Mutton Bird Island, Balls Pyramid)

Priorities for conservation management

Here we propose an area-based classification scheme as a framework for dealing with current and future conservation management issues for vascular flora on Lord Howe Island. This should then be overlain on and integrated with issues for non-vascular flora, fungi and fauna, where such information is available. We identify six priority areas for management based on the overall conservation significance of the vascular flora of each area, in combination with the nature and degree of threats that are either currently impacting on the vegetation or may rapidly impact on the vegetation in the future. While there is clear overlap between vegetation across areas, each area stands as a unit that can be practically managed on the ground. It is also possible that subdivision of the suggested areas may be practical for management but here we simply present the overall broadscale priorities. A summary of the priority areas and major threats is contained in Table 1, while the key actions for management of vascular flora conservation are contained in Table 2.

Priority 1. Southern Mountains and Intermediate Hill

This area covers some 65% of the main island and contains all vegetation in the Permanent Park Preserve south of the airstrip. Because of the connectivity of the vegetation, it is important to manage it as a single unit. Some of the area has been cleared (south end of Lagoon beach through to Salmon Beach), but most is rugged and uncleared. The area is of the highest priority in terms of conservation of vascular flora. It contains the majority of endemic species and significant endemic plant communities such as cloud forest, Mountain palm forest, *Chionanthus* closed forest and *Dracophyllum/ Metrosideros* scrub (Pickard 1983a). The endangered species *Carmichaelia exsul, Coprosma inopinata, Geniostoma huttonii, Polystichum moorei* and *Xylosma parvifolium* are confined to this area, while three of the four known

Table 1. Priority Areas and Key Threats to conservation of vascular flora (see Fig. 1 for locations).

Priority	Area	Key Threats
1	Southern Mountains & Intermediate Hill	Weeds, climate change, *Phytophthora cinnamomi*, rodents
2	Transit Hill	Weeds, dieback of forest edges
3	Northern Hills	Weeds, dieback of forest edges
4	Settlement Area	Weeds, edge disturbances, *Phytophthora cinnamomi*, degradation and loss of *Lagunaria* swamp forest, genetic pollution
5	Coastal Dunes	Weeds
6	Offshore Islets	Weeds on Blackburn Island

populations of the endangered *Calystegia affinis* occur here. Several rare species or species of conservation significance also occur here (Pickard 1983b, Hutton 2001, unpubl., Harris et al. in press). There are also a number of significant non-vascular plants, particularly on mountain summits, and a range of significant vertebrate and invertebrate species (Cassis et al. 2003). At present, this area is not as severely impacted as are the Transit and Northern Hills areas (priority areas 2 and 3), but it is essential that that degree of degradation is precluded from occurring in the southern mountains.

For the conservation of the flora, key issues are: weed encroachment, climate change, ensuring the habitat remains free of *Phytophthora cinnamomi*, maintenance of negative impacts of walking tracks and associated users, rodent impacts and rehabilitation of *Lagunaria* Swamp Forest at former locations.

Weeds

As the settlement is the source of weeds into this unit, the worst infestations of weeds are close to the disturbed areas. However, weeds will spread from this edge throughout the southern mountains if left unchecked. As well there are a number of weeds that can invade undisturbed native vegetation on Lord Howe Island (Pickard 1984). Already individuals of serious weeds such as *Psidium cattleianum* have been found on the upper slopes of both Mount Gower and Mount Lidgbird. Three main groups of weeds are serious problems for this area.

(1) *Fleshy-fruited weed species that have the ability to modify the understorey structure of the forests of the southern mountains.* Within this area there are several areas of land that are now part of the Permanent Park Preserve, but were cleared as leases in the 1950s. These contain many weed species including *Psidium cattleianum*, which are a source of weed invasion into the undisturbed forests. A belt of *Psidium cattleianum*, occurs all along the boundary of the settlement area here and already numerous individuals of *Psidium cattleianum* occur within the forest of the Permanent Park Preserve. There are scattered individuals occurring on remote north slopes of Mount Gower to 600 m elevation. Other fleshy-fruited weeds in this belt include *Cotoneaster glaucophyllus*, *Ochna serrulata*, *Chrysanthemoides monilifera* and *Asparagus aethiopicus*. If left unchecked, these species have the potential to dramatically reduce the conservation values of this, the highest priority area.

Two ways of dealing with weed invasions in these types of areas are:

(a) to treat mature fruiting individuals to prevent further seed dispersal; and

(b) the Bradley Method (Bradley 1988) i.e. to start at the farthest, sparsely separated individuals and work back to the worst areas near the source of infestation (usually settlement areas).

The most effective treatment may be to combine these methods. Any large stands of mature plants that are a seed source, and are easily accessible can be treated to prevent seeds being available for further spread. When planning long term works programs it may be effective to divide the area into a grid, and to start treatment of grids at the extreme ends of weed infestation, working back to the centre of most dense infestations.

Low numbers of fruiting *Psidium cattleianum* have already been removed from the remote slopes of Mount Gower and Mount Lidgbird to 600 m altititude. A surveillance program needs to be introduced to search the most likely remote areas for these weeds and remove them. If left, they become a source to develop into major remote infestations. The sites most likely to have these weeds are open, sunny areas (but they can also recruit into undisturbed forest). These areas include the boundary of the vertical cliffs and heavily forested slopes at around 400 m, open slopes with low sparse scrub, and landslips. The north and west faces with more sun are more prone to weed invasion.

The areas of worst weed infestation have been mapped to identify areas for treatment (Lord Howe Island Board 2002b, Le Cussan 2003). As weed control work is done, this work should also be mapped to evaluate treatment programs as they proceed.

(2) *Wind-dispersed weed species.* Currently these are a major problem on the exposed edges of the rocky slopes of the southern mountains and habitat in areas at the base of the major cliffs where torrents of water from creeks, flowing during heavy rainfall, scour native vegetation. This distribution probably results from past goat activity and ongoing high level of environmental disturbance due to the exposed nature of such sites. Major problem species are *Ageratina adenophora* (Crofton weed) and *Lilium formosanum*. Such species tend to locally dominate the exposed sites and exclude natives. *Ageratina adenophora* has probably been on Lord Howe Island since the 1920s (Pickard 1984). It occurs at many areas around the whole of Mount Lidgbird and Mount Gower at about 400m in elevation. From these dense, almost monoculture areas it is spreading into other exposed mountain slopes, particularly on Mount Gower.

Table 2. Key actions for conservation management of vascular plants on Lord Howe Island.

Issue	Action
Weed control	Focus resources on highest priority conservation areas, independent of current magnitude of weed problem. This may involve some modification to existing weed eradication/control programs. A 'surveillance program' and a 'rapid response' program should be developed to quickly identify and treat any new weed incursions into the island. Early detection and treatment have been identified as the number one factor in successful eradication of weeds. Involve the community in this program. This is essential to reduce the rate of new weed introductions. Removal of potential environmental weeds from Settlement area in co-operation with community. Continue support for volunteer program for assisting with weed eradication. Monitor walking tracks for weed incursions. Treat weed control as one component of habitat restoration.
Public awareness	Continuing public awareness program about the need to protect the forests. This is for the integrity of the islands ecosystems and to maintain the island as a high quality ecotourism destination. This includes treating weeds on leases and removal of garden plants that are potential weedy species. Removal of exotic species that may pollute the genetic diversity of endemic species. Continuing public awareness program about not bringing foreign plants and animals to the island. Continue to supply Lord Howe Island native plants to residents for landscaping and gardens. Consider expanding the range of plants available, to also include native ferns and ground cover such as native grasses.
Quarantine	Develop and implement strategy for control of spread of *Phytophthora cinnamomi.* Implementation of the quarantine strategy adopted by the Lord Howe Island Board.
Rehabilitation	Focus on dieback areas and *Lagunaria* swamp forest. Continue rehabilitation programs already in place.
Research	Priority areas being weed control, restoration, conservation assessment, rodent impacts, population dynamics, *ex situ* conservation of endemic cloud forest species. Continual research into up to date treatment methods of all weeds where they occur in other parts of the world, particularly islands. Introduce staff to these latest methods. Support investigation into biology and ecology of major weed species to aid an understanding of potential spread and possible control strategies. Investigate current research into biological control of all weed species. Research possible sources of funding into biological control of all weeds, in particular Crofton weed *Ageratina adnenophora.* Monitor effectiveness of current weed program and methods. Continue research into rodent eradication, but quantify vegetation impacts and prioritise species and areas for control prior to eradication.
Funding	Continue to seek long term funding for a range of projects. Encourage collaborate research through ARC linkage grants for particular issues.

The location of these wind-dispersed weed species makes manual control largely impossible. At the same time they are having a serious impact on the World Heritage Values of Lord Howe Island and seriously impact on threatened plant species including the endangered *Carmichaelia exsul* and *Calystegia affinis*. Biological control may be a future option for control of some of these weeds and given the high number of Lord Howe Island endemic species, research into such control should be a national priority.

(3) *Weeds recently carried into the southern mountains area along walking tracks.* These are currently only very localised and are having a minor impact, but their removal would be simple and cheap now; delaying any action will make control more expensive and perhaps impossible. Examples include *Paspalum wettsteinii* which occurs in about four places on the Muttonbird Point-Rocky Run- Boat Harbour track and at one place in Erskine Valley on the Mount Gower track. Kikuyu grass, *Pennisetum clandestinum,* occurs at only one place near the start of the Muttonbird Point Track, but also occurs on the Mount Gower walking track below Mount Lidgbird and at 700m in elevation. Treatment and removal of these weeds now will maximise the environmental benefit and be the most cost effective way to deal with them.

Weed control is just one component to the final outcome which should be habitat restoration. When a weed is treated or removed, other weeds may invade the area; it may be necessary to monitor the site and undertake other actions. Many weed species grow best in sunny open conditions, and are suppressed in shade so effective restoration may require mulching and/or planting native species to provide shade and inhibit weed species. Other species can invade and persist in shaded habitats or undisturbed forests (Pickard 1984) and ongoing control will be needed.

Table 3. Species from Lord Howe Island with conspecifics elsewhere in the world that have been impacted by *Phytophthora cinnamomi*.

Lord Howe Island Species	Importance on Lord Howe Island	Conspecific affected elsewhere
Cassinia tenuifolia	Widespread shrub of lowlands. Major recolonising species	*C. aculeata* eastern Aust. (Taylor 1974)
Coprosma huttoniana	Endemic shrub of upper southern mountains	*C. australis* in New Zealand (McKenzie et al. 2002)
Coprosma inopinata	Endangered endemic shrub of upper mountains	*C. australis* in New Zealand (McKenzie et al. 2002)
Coprosma lanceolaris	Endemic shrub of upper southern mountains	*C. australis* in New Zealand (McKenzie et al. 2002)
Coprosma prisca	Endemic lowland shrub	*C. australis* in New Zealand (McKenzie et al. 2002)
Coprosma putida	Endemic small tree of lowlands to mountains	*C. australis* in New Zealand (McKenzie et al. 2002)
Cryptocarya gregsonii	Endemic tree of southern mountains	*C. cinnamomifolia, C. corrugata, C. glaucescens* Tropical Queensland (Brown 1999)
C. triplinervis	Major dominant tree on lowland forests	*C. cinnamomifolia , C. corrugata, C. glaucescens* Tropical Queensland (Brown 1999)
Dodonaea viscosa	Widespread shrub to small tree of lowlands	*D. viscosa* eastern Aust. (Taylor 1974)
Drachophyllum fitzgeraldii	Endemic tree, major structural component in southern mountains	A range of Epacridaceae
Exocarpus homalocladus	Widespread endemic shrub to tree	*E. cupressiformis* eastern Aust. (Taylor 1974)
Gahnia howeana	Endemic shrub from lowlands to mountains	*G. xanthocarpa* in New Zealand (McKenzie et al. 2002)
Gonocarpus sp.	Confined to ridge of Mt Gower	*Gonocarpus teucrioides* (Pratt & Heather 1973)
Leptospermum polygalifolium spp. *howense*	Endemic subspecies of shrub or small tree important structural component of cloud forest	*L.* spp. eastern Aust. (Taylor 1974, Weste 1974, Podger & Brown 1989)
Leucopogon parviflorus	Lowland shrub	*L.* spp. eastern Aust. (Pratt & Heather 1973, Taylor 1974, Barker & Wardlaw 1995)
Metrosideros nervulosa	Endemic small tree of southern mountains	*M. collina* in Hawaii (Kliejunas and Ko 1976)
M. sclerocarpa	Endemic tree of southern mountains	*M. collina* in Hawaii (Kliejunas and Ko 1976)
Olearia ballii	Shrub of southern mountains	*O. oppositifolia* Barrington Tops (McDougall & Summerell unpubl.)
Olearia elliptica ssp. *praeternissa*	Endemic subspecies of shrub from southern mountains	*O. oppositifolia* Barrington Tops (McDougall & Summerell unpubl.)
Olearia mooneyi	Endemic small tree of southern mountain tops	*O. oppositifolia* Barrington Tops (McDougall & Summerell unpubl.)
Syzygium fullageri	Major structural endemic tree of lowlands and southern mountains	*S. erythrodoxa, S. wesa* Tropical Queensland (Brown 1999)
Symplocos candelabrum	Endemic tree of southern mountains	*S. stawellii* Tropical Queensland (Brown 1999)

Exclusion of pathogen Phytophthora cinnamomi

This pathogen has recently been identified as occurring in an avocado orchard on the island. A number of taxa from the southern mountains are potentially susceptible to this pathogen, based on related species elsewhere. These include major structural dominants such as *Syzygium, Dracophyllum, Metrosideros, Leptospermum* and *Cryptocarya* (Table 3). The pathogen could devastate the vegetation. Currently, a precautionary approach should be taken and protocols for prevention of the pathogen from reaching the southern mountains should be developed, along with testing of potentially susceptible taxa in Table 3.

With human visitation increasing, the possibility of this pathogen (or others) being introduced on walking boots is increasing. Visitors to Lord Howe Island should be advised to clean and treat their walking shoes and boots before travelling to the Island. A treatment station at the starting points to walking tracks in this area is needed to prevent pathogens being carried into vegetated areas.

Climate change

The most likely impact of climate change will be on the cloud forest and associated vegetation and fauna of the southern mountains. While control of the issue is not relevant for Lord Howe Island, it may be possible to reduce the potential impacts of climate change. This would require ensuring species confined to the cloud forest and upper mountain slopes have representative samples in *ex situ* conservation, including seedbanks and living collections.

Rodent control

A number of plants in this area have seeds, fruits or vegetative material that are consumed by introduced rodents. For example, observations on Mount Gower have suggested that recruitment of *Lepidorrachis moorei* (Small Mountain Palm) has been limited by rodents and that effective recruitment only occurs in areas subject to rodent poisoning.

A quantitative assessment of the standing size structure of the population on Mount Gower is needed. This should include a comparison across baited and non-baited areas as well as assessing the survival of tagged seedlings and juvenile plants. This will demonstrate the importance of rodent control for the small mountain palm.

The extent of impact of rodents on other species is poorly known and research in this area should be encouraged. It is possible that rodents may be eating fruits of *Passiflora herbertiana* ssp. *insulae-howei*, a species that is highly restricted and declining on Lord Howe Island (Pickard 1983b, Hutton unpubl.).

Priority 2 Transit Hill

This area is crown land that is proposed for addition to the Permanent Park Preserve. It contains both *Drypetes/Cryptocarya* closed forest, *Howea forsteriana* palm forest and mixed forest (Pickard 1983a). The area is largely intact but, being close to the settlement area, has been subject to weed invasion (Le Cussan 2002) and edge disturbances in particular. This is a second priority area as mature individuals of weed species in this area are a potential source of seeds that birds may carry into the southern mountains. Weed eradication should start from the southern end of this area and work north. The proposal to reconstruct a narrow vegetation corridor between Transit Hill and Intermediate Hill (to the south) (Lord Howe Island Board 2002a) should consider the possible negative impacts of the increased access of weed seeds to the southern mountains by dispersal from birds. Simberloff and Cox (1987) and Simberloff et al. (1992) have highlighted the need to consider a range of issues that may degrade the areas linked by corridors. The possibility of increased weed invasion is one such issue. Given that the highest conservation value area on Lord Howe Island is the southern mountains and that bird dispersed weeds are a major threat to this area, a quantitative assessment of the potential impact of such a corridor is needed before it proceeds.

Weeds

A number of weed species are a major concern in this area (Pickard 1984, Le Cussan 2002) including bird-dispersed *Psidium cattleianum*, *Cotoneaster glaucophyllus*, *Pittosporum undulatum*, *Asparagus aethiopicus* and *Asparagus plumosus*.

Since 2000, staff from the Lord Howe Island Board have been treating the major woody weeds in this area. Since 1998 volunteer teams from mainland Australia have been assisting the Lord Howe Island Board with treatment and removal of *Asparagus aethiopicus* and *Asparagus plumosus*. A group of 20 volunteers usually contribute around 400 hours per week, and now each year six groups participate. These groups of volunteers are an important resource for readily accessible weed-infested areas.

Dieback of forest edges

Restoration trials and research into dealing with edge effects on the boundary of pasture and forest should be undertaken.

Priority 3 Northern Hills

The northern hills contain a number of species and communities largely restricted to the northern end of Lord Howe Island. Vegetation is a mixture of *Drypetes/Cryptocarya* closed forest, *Howea belmoreana* and *Howea forsteriana* palm forests, *Syzygium fullageri* closed forest and small areas of scrub and *Atriplex* dwarf scrub (Pickard 1983a). A number of rare or threatened plants occur in this area (Pickard 1983b). The rare orchids *Plectrorrhiza erecta* (an endemic) and *Corybas barbarae* (an outlier also occurring in eastern Australia) are confined to this area (Hutton 2001). A population of the endangered *Calystegia affinis* occurs on the boundary of the northern hills and the settlement area, as does the endangered ecological community *Lagunaria* swamp forest. However, the floristic diversity and habitat complexity of the area is not as great as the southern mountains and there is greater degradation of the area due to weeds, and hence, the lower relative priority of this area. The main threats in this area are weeds and dieback along pasture/forest edges.

Weeds

The northern hills have been invaded by weeds that have escaped from the settlement area, mainly *Chrysanthemoides monilifera*, *Asparagus aethiopicus* and *Asparagus myrsiphyllum*. Some weeds are still escaping (*Ligustrum sinense*, *Cotoneaster glaucophyllus*, *Grevillea robusta*). Since about 1985 there have been periodic sweeps through this area by Lord Howe Island Board staff for eradication of *Asparagus aethiopicus*. More recently work has been done on *Asparagus myrsiphyllum* near Kims Lookout, including release of a biological control agent (a rust). Two infestations of *Pennisetum clandestinum* (Kikuyu grass) occur in this northern section of the Permanent Park Preserve and should be removed as they continue to spread each year (Dawsons Point and the west end of North Beach). Control of garden plants escaping into this forest and becoming the environmental weeds of the future is essential. There needs to be a program for removal of potential environmental weeds from the adjacent settlement area.

Dieback of forest edges

Restoration trials and research into dealing with edge effects on the boundary of pasture and forest should be undertaken.

Priority 4 Settlement Area

The settlement area has been extensively cleared and the remaining vegetation is severely fragmented and disturbed with large edge effects. The NSW endangered plant *Caesalpinia bonduc* is known from this area. Major threats include weeds, edge-related habitat disturbances, maintenance and restoration of the endangered *Lagunaria* swamp forest ecological community, *Phytophthora cinnamomi*, and genetic pollution.

Weeds

This area is the source of most weed species and the exponential increase in exotic introductions to Lord Howe Island (Pickard 1984) is continuing (Hutton & Auld unpubl.). This demonstrates a failure to deal with the major problem of importation of exotics to Lord Howe Island. As well as the 17 species of plants listed by the Lord Howe Island Board as noxious weeds under NSW legislation, Hutton and Le Cussan (2001) identified a further 36 plant species in the settlement that are already on the way to being, or could already be, environmental weeds. Continued degradation of the World Heritage Values of Lord Howe Island will occur unless this rate of introduction of weeds is greatly reduced.

A program is needed to make residents aware of the potential threat of weed species and seek the removal of potential environmental weeds in the settlement area (Table 2). This could include continuing public awareness campaigns, Lord Howe Island Board staff removing such species from crown land, Board staff assisting with removal from private leases, and the Board providing native Lord Howe Island plants to replace those removed.

Recent years have seen attempts to make the resident community more aware of the weed problem but more work needs to be done to promote awareness of weed threats to the integrity of the Island's forests, and its future as a prime ecotourism destination. Staff of the Lord Howe Island Board conduct regular lease inspections and advise leaseholders of problems and responsibilities. Good relations in this area have seen progress in cooperation with residents for removal of noxious weeds. This needs to continue.

One weed which should be taken more seriously in the settlement area is *Anredera cordifolia* (Madiera vine). Only introduced in the 1970s, some control was started on this in 1980 by the Lord Howe Island Board (Hutton pers. comm.) and it could have been eradicated by now, if the effort had continued. This is one of the worst environmental weeds on Raoul Island (Kermadec group), an island with similar climate and geology to Lord Howe Island. *Anredera cordifolia* is such a potential threat to Lord Howe Island's forest ecosystems that the Lord Howe Island Board should take responsibility for its eradication, rather than leaving control to leaseholders.

Edge-related habitat disturbances

It is still necessary to protect and revegetate edges of remnants in the settlement area to prevent continual degradation along edges as suggested over 20 years ago by Pickard (1983a).

Maintenance and restoration of Lagunaria *swamp forest*

This ecological community is listed as endangered on the NSW *Threatened Species Conservation Act*. The community is largely confined to the Settlement area (see Pickard 1983a). Much of the community has been cleared and only a few highly disturbed remnants remain, many of which are on the boundary of the former community distribution. Threats to the community are clearing, grazing, weeds and alterations to water regimes. Some restoration of this community will be needed to ensure the tiny remnants can persist. This may involve weed control and rehabilitation plantings using local stock from remnants of this ecological community. The progress of establishment of any plantings will need to be monitored. Some exclusion fencing to reduce stock grazing impacts on rehabilitation will also be needed.

Genetic pollution of endemics

The settlement area contains a number of introduced ornamental plant species that have endemic species from the same genus. For example *Metrosideros excelsa* on lagoon foreshore and at Neds Beach; *Dietes* sp. from Southern Africa in gardens, *Coprosma repens* in gardens and at Neds Beach. These introduced plants should be removed to prevent cross pollination and dilution of the genetic integrity of endemic species.

The pathogen Phytophthora cinnamomi

This pathogen has recently been identified (B. Summerell pers. comm.) as occurring in an avocado orchard on the settlement area of the island. Active quarantine measures are needed to ensure that it does not spread to other parts of Lord Howe Island.

Priority 5 Coastal dunes

The coastal dunes on Lord Howe Island are a relatively homogenous vegetation type that occur in several different parts of Lord Howe Island (Pickard 1983a). The NSW *TSC Act* listed endangered plant *Chamaesyce psammogeton* occurs on these coastal dunes. The major threat to these dunes is weed invasion.

Weeds

The dune areas at many locations around the settlement have been severely invaded by introduced grass species, mainly *Stenotaphrum secundatum* (Buffalo Grass) and some areas of dunes could be targeted in future rehabilitation programs to restore to natural systems.

The beach dunes can be invaded by weeds that have recently arrived on the mainland Australia and float to Lord Howe Island. Three weed species that have probably arrived this way are *Ipomoea cairica*, *Cakile edentula* and *Euphorbia paralias*; the latter is only occurring on a small area of Lagoon Beach at present and every effort should be made to eradicate it now. Regular inspection of dunes should be part of the weed program, and early detection and treatment of new arrivals can be carried out. The condition of the dunes varies across Lord Howe Island, with a number of dunes degraded by weeds. Some weed control is needed. Any re-planting to replace weeds in restoration programs must use local stock to maintain local genetic integrity, as there is evidence of species being imported to Lord Howe Island from mainland NSW in previous restoration works on the dune near the airport.

Priority 6 Offshore islets

These islets are an important part of the landscape of Lord Howe Island but because of their relative isolation from the main island, and difficulty of access, they are generally free from major weed species and rodents, and threats are minimal. However monitoring of weed species should be carried out.

The exception is Blackburn (or Rabbit) Island in the lagoon which has been grazed by introduced animals in the past and is now largely covered by the introduced *Chloris gayana* (Rhodes Grass). It is an important seabird breeding island (Wedge-tailed Shearwaters) and a refuge for a several of Lord Howe's endemic animals that have been lost or greatly reduced on the main island. These include the two lizard species *Christinus guentheri* and *Pseudomia lichenigerum* and the endangered *Panesthesia lata* (Lord Howe Island Bush Cockroach).

The original vegetation of Blackburn Island may have included some tree or shrub species, but probably had similar plant species to that found on the offshore islets such as Roach Island. Careful treatment and monitoring of the introduced Rhodes grass may allow native species such as *Commelina cyanea*, *Acaranthes aspera* and *Canavalia rosea* to establish and provide ground cover to exclude weeds, and allow protection for the seabirds to breed. In time, seeds of trees or shrubs from those still remaining on the island may colonise parts of this island.

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Floristic communities of the lower Dawson River plains, mid-eastern Queensland

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Abstract: Floristic communities from the alluvial floodplains and near-alluvial plains of the lower Dawson River, mideastern Queensland, are described from near-intact sites. Three broad and ten detailed floristic groups were defined. Differences in community composition appeared related to soil type, localised disturbance and latitude. Weeds comprised a small proportion of the total flora, although they presently dominate some areas. Grasses were the main exotic species present, and appeared to have increased within the last forty years.

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Introduction

Floodplain ecosystems in sub-coastal Queensland have been comparatively little studied, despite a long history of gross modification through construction of impoundments. The plains of the lower Dawson River are no exception, although there have been useful investigations into the health and condition of the riparian zones of this system (Telfer 1995). Recent floristic studies of the lower Dawson River have been limited to the potential inundation area of the proposed Nathan Dam project (Dowling & Halford 1996).

The Nathan Dam, a new large-scale water storage on the lower Dawson River, will provide a significant water source for broad-scale, intensive irrigation purposes. Reliability of supply has been recognised as a major limitation for expansion of cultivation in the region (Speck et al. 1968, Gillespie et al. 1991). Intensification of regional land use heralds great changes in an already modified and disturbed floodplain system (Telfer 1995, Eberhard 1999), especially downstream of the impoundment. Elsewhere in Australia, altered flood regimes resulting from river regulation have had negative impacts on regeneration of riparian vegetation, such as *Eucalyptus camaldulensis* dominated systems (Stefano 2002). However, the effects of changes in Dawson River flow regimes on downstream ecosystems reliant upon flood inundation remain poorly understood (Eberhard 1999).

Kingsford (2000) outlined the lack of detailed baseline ecological information on floodplain ecosystems throughout Australia, and noted that assessment of the impact of structures such as dams on these ecosystems is therefore problematic. This study aims to outline the floristic associations on floodplains and clay-plains of the lower portion of the Dawson River system. Such information may provide a snapshot with which future floristic changes can be measured.

Study area

Location

The study area is located within the Brigalow Belt South bioregion (Thackway & Cresswell 1995). It extends from a southerly point immediately upstream of the Gyranda Weir, west of Cracow (25°11'S, 148°15'E) north to the junction with the Mackenzie River (23° 35'S, 149°44'E), some 180 km in length (Fig. 1). The major towns of Theodore, Baralaba and Moura occur within or closely adjacent to the area studied.

Landforms and soils

This study examined near-level alluvial floodplain systems of the lower Dawson River, as well as in-stream channels and depressions. It also included flat areas of undulating clay downs adjacent to the alluvial plain, although these are considered as two different broad geological categories (Sattler & Williams 1999).

Plains landforms are widespread in the Dawson River region (Speck et al. 1968). The fluvial plains of the lower Dawson River vary in width between 0.2 to 12 km, consisting of both stable and unstable trunk plains. Elevated depositional clay plains flank the alluvial systems, and extend a further 2–4 km from their outer edge. Speck et al. (1968) described the land systems of the alluvial and near-alluvial systems within the study area. Soils of these plain landforms are typically vertosols or dermosols, or less frequently chromosols or sodosols (McCarroll 1996, after Isbell 1996). These soils were derived from Upper Palaeozoic volcanic or sedimentary rocks and Mesozoic shales. Significant local differences in soil texture and chemistry were apparent (Speck et al. 1968, McCarroll 1996).

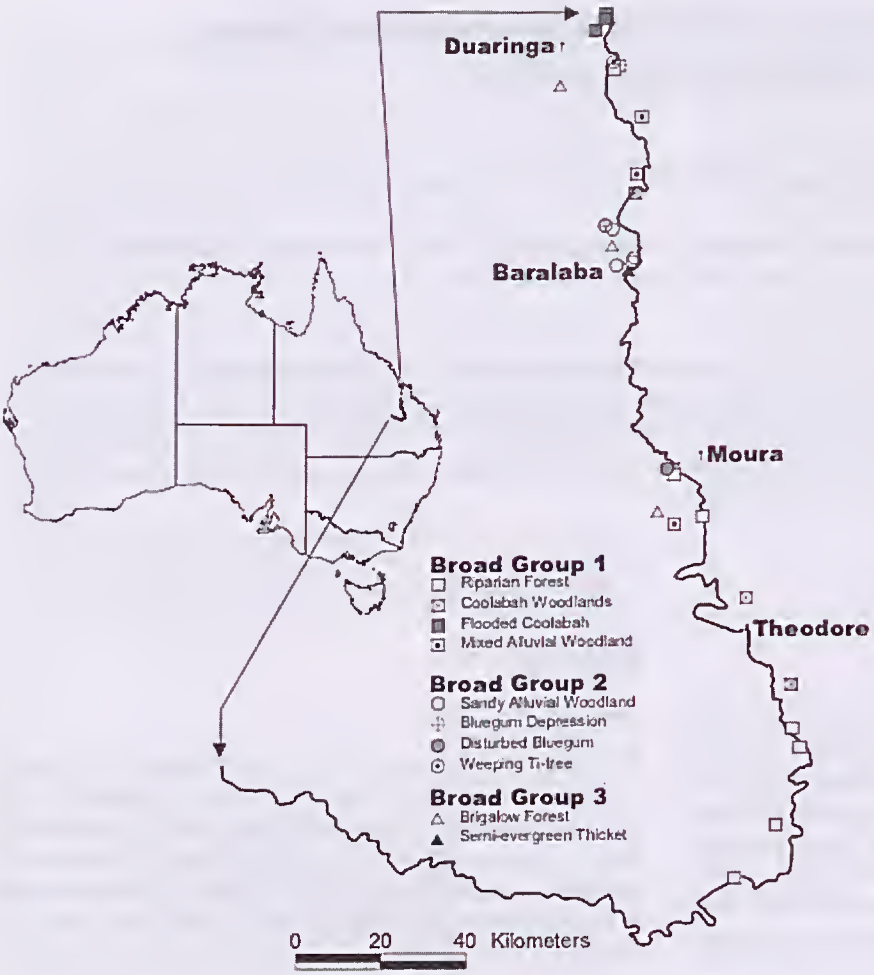

Fig. 1. Map showing the location of the study area and the distribution of sites and floristic groups along the lower Dawson River.

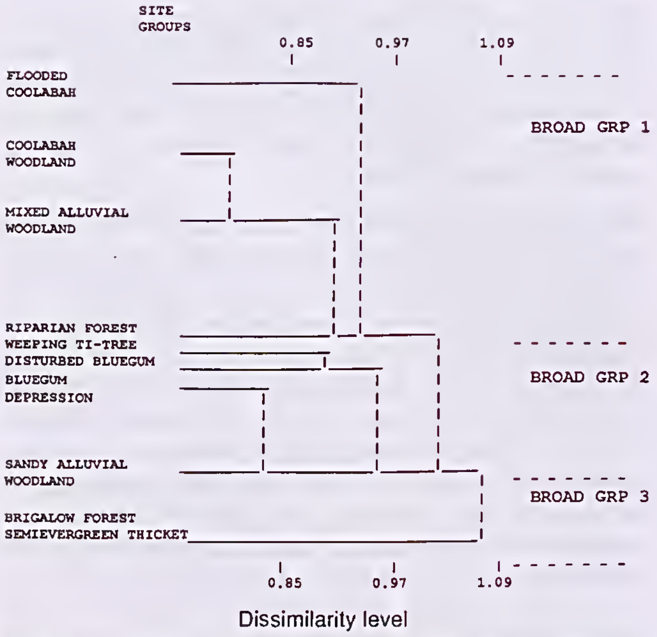

Fig. 2. Summary dendrogram of the PATN analysis of the Dawson River sites using the Kulezynski association measure, flexible UPGMA fusion strategy and a beta value of -0.1. Communities have been discerned at c. the 0.75–0.8 dissimilarity level, however an arbitrary uniform level was not chosen, as per Clarke et al. (1998).

Methods

Site data collection

A total of 30 detailed sites from the CORVEG database of the Queensland Herbarium were used in the analysis. All sites chosen sampled vegetation on alluvium and clay-plains and all of the major woodland vegetation types within the study area were sampled. A typical CORVEG quadrat was a 10 × 50 m plot (Neldner et al. 2004). The height and crown cover of trees and shrubs were recorded across the site, while foliage projected cover (FPC) was recorded for grasses and forbs in the ground layer. Sampling was undertaken from May 1997 to June 1999, during broadscale mapping projects within the region. CORVEG sites were located in areas subjectively considered undisturbed from recent heavy grazing or mechanical disturbance.

Identification and nomenclature

All vascular plants collected at detailed sites were identified using the resources of the Queensland Herbarium. Sampling spanned a number of years and conditions were poor for collection and identification of grasses and herbaceous taxa in some seasons. Thus some annual or ephemeral species have certainly been missed. Where good quality specimens were obtained, vouchers were lodged with the Queensland Herbarium (BRI). Botanical nomenclature followed Henderson (2002). An asterisk (*) denotes non-native species.

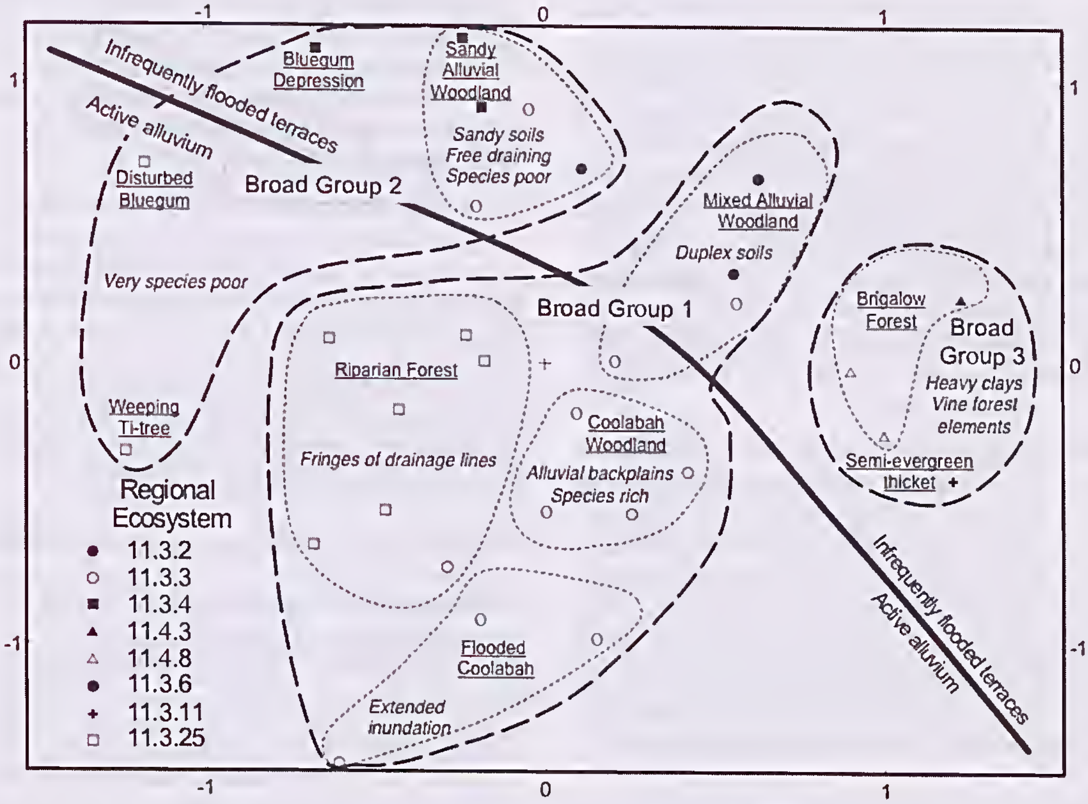

Fig. 3. Ordination diagram (MDS) illustrating floristic association between groups of sites (within fine dashed lines) within Broad Groups (heavy dashed lines) and notes on physical habitat characteristics. Site symbols indicate Regional Ecosystems, which are the basic biodiversity plannning units in Queensland (Sattler & Williams 1999).

Analyses

Floristic analysis of site data used the subroutines within PATN (Belbin 1993). A hierarchical classification with flexible UPGMA (Unweighted Pair-Group Mathematical Averaging) and the Kulczynski association was used to prepare a dendrogram outlining floristic groups. Additional analysis was completed using multi-dimensional scaling (MDS) within PRIMER (Anonymous 2000), using the Czechanowski Index of similarity. Both analyses were based on the presence/absence of all species recorded for a plot.

Results

Sampling intensity was relatively low, with 30 sites sampling about 24 000 ha of remnant vegetation (Pollock & Edginton 1999), or 1 site/800 ha. While sampling effort must be considered low relative to some recommendations (e.g. (Neldner et al. 1995), it was well above limits prescribed for the original mapping projects the sites were derived from (Neldner et al. 2004).

Floristics

A total of 312 vascular plants were recorded within the study area. This included site data from this study, and historical and recent collections recorded on the HERBRECS database (Appendix 1). Poaceae dominated the flora (24 %), with Myrtaceae (6 %) and Cyperaceae (5 %) also prominent.

Rare species

The fan-palm *Livistona nitida* is listed as Rare under the Queensland *Nature Conservation Act (1992)* and is locally common along the Dawson River from north of Theodore, south to the southern boundary of the study area. *Livistona nitida* is endemic to the Dawson River and its upper tributaries (Rodd 1998) and forms a characteristic component of some riverine forests in the study area (Pollock & Edginton 1999).

Geographical limits

Taxa reaching their northern limits within the study area included: *Livistona nitida* (about 20 km north of Theodore); *Carex rhytidocarpa* (south-west of Theodore) and **Phyla canescens* (near Moura). Species reaching their southern limit included: *Corymbia dallachiana* (near Duaringa); *Melaleuca leucadendra* (Boolburra area); *Terminalia oblongata* (near Moura); *Abutilon asiaticum* var. *australiense* (near Mackenzie/Dawson River junction); *Lysiphyllum hookeri* (Dawson River near Nipan) and **Echinochloa polystachya* (near Moura).

Introduced species

Introduced taxa made up about 15 % of the known flora. The nine most common introduced plants observed in quadrats, in order of decreasing abundance (percent occurrence in brackets), were **Megathyrsus maximus* var. *pubiglumis* (37%), **Cenchrus ciliaris* (33%), **Senna barclayana* (23%), **Melinis repens* (20%), **Opuntia stricta* (20%), **Gomphrena celosioides* (13%), **Verbena* spp. (10%), **Acacia farnesiana* (10%) and **Bidens pilosa* (10%). Most of these species are typical of grassy woodlands across subcoastal Queensland. However, **Acacia farnesiana* is widespread on heavy clays and clay alluvia across Queensland (HERBRECS records), and was also frequently recorded in floodplain woodlands in inland NSW (Gosper et al. 2002).

Weeds of national significance (Thorp & Lynch 2000) present in the study area included **Parthenium hysterophorus* (present near Mimosa Creek/Dawson River junction); **Parkinsonia aculeata* (downstream of Don River/Dawson River junction) and **Cryptostegia grandiflora* (scattered downstream from the Knebworth area). Other significant weeds included **Hymenachne amplexicaulis* (present at Baralaba Weir), **Xanthium pungens* (widespread in *E. coolabah* and *E. camaldulensis* woodlands and forest), and **Bryophyllum delagoense* (present in small areas of semi-evergreen thicket on alluvia).

Environmental weeds, defined after Batianoff and Butler (2002), were conspicuous within most vegetation types. Introduced grasses were prominent, as observed earlier by Telfer (1995). The most widespread were **Megathyrsus maximus* var. *pubiglumis*, **Urochloa mosambicensis*, **Melinis repens* and **Cenchrus ciliaris*. The first two species were common in disturbed grassy woodlands on dark vertosols subject to flood inundation, such as *Eucalyptus coolabah* or *E. camaldulensis* grassy woodlands. The latter species were more common in better-drained, less frequently flooded situations, in areas dominated by *Corymbia tessellaris*, *Eucalyptus populnea* or *Eucalyptus tereticornis*. These responses to soil type illustrate the relative drought tolerance of these invasive exotic species (Williams & Baruch 2000).

Floristic associations

Classification of the thirty plots suggested three broad vegetation groups (Figs 1, 2 & 3). These were strongly correlated with soil type, landform element, and proximity to the main river channel.

Broad Group 1 encompassed predominantly grassy *Eucalyptus coolabah/Eucalyptus camaldulensis/Eucalyptus populnea* communities, with associated *Eucalyptus tereticornis/Lophostemon suaveolens* on or near levees. This broad group occurred frequently on dark vertosols. It was characterised as having a ground layer rich in grass or forb species. This group was always associated with alluvial plains.

Broad Group 2 was a set of sites occurring generally on deep sandy substrates associated with backplains or along sandy river channels. Predominant species were mainly *Eucalyptus tereticornis* and *Corymbia tessellaris*, with a ground layer of only a few species of grass or forb. Broad Group 2 was associated with light brown chromosols, often on broad stable levees.

An *Acacia harpophylla/Eucalyptus cambageana*/semi-evergreen thicket community formed Broad Group 3, occurring on very heavy vertosols or kandosols. This group was characterised by having a large number of tree and shrub species, with a comparatively species poor ground layer.

These three broad types were subdivided into ten floristic site groups, which were given descriptive names. The association of floristic groups with one another and with physical habitats is illustrated in Figure 3.

Broad Group 1 included four floodplain communities

Flooded Coolabah *Eucalyptus coolabah* (3 sites)

Species richness: 8–26 Mean species/site : 18.3
Mean weed species/site: 4.6 Mean total weed cover/site: 0.5 % FPC

This community included species such as *Eucalyptus coolabah*, *Basilicum polystachyon*, *Eustrephus latifolius*, *Abutilon asiaticum*, *Lysiphyllum carronii*, *Marsilea drummondii*, *Muehlenbeckia florulenta*, *Sporobolus mitchellii*, *Eriochloa pseudoacrotricha*, *Tetragonia tetragonioides*, *Alternanthera nodiflora* and **Parkinsonia aculeata*. Flooded Coolabah was characterised by landforms such as low-lying river channels and small billabongs that were subject to regular convergence flooding by the Dawson and Mackenzie Rivers. All sites were dominated by *Eucalyptus coolabah*, with a ground layer of species characteristic of prolonged inundation. Flooded Coolabah woodlands occurred consistently on heavy, dark grey to black vertosols that remained wet for long periods.

Coolabah *Eucalyptus coolabah* Woodland (4 sites)

Species richness: 26–44 Mean species/site: 37.2
Mean weed species/site: 6.5 Mean total weed cover: 6.0 % FPC

Coolabah Woodland always contained a tree layer of *Eucalyptus coolabah* with a sparse to mid-dense shrub layer of *Acacia salicina*. A diverse ground layer was evident, typically with *Achyranthes aspera*, *Cyperus gracilis*, *Bothriochloa bladhii*, *Cymbopogon refractus*, *Heteropogon contortus*, *Leptochloa decipiens*, **Malvastrum americanum*, **Sida spinosa*, and **Senna barclayana*. The epiphyte *Cymbidium canaliculatum* was almost always present within hollows of mature *E. coolabah*. Frequent weeds were **Megathyrsus maximus* var. *pubiglumis* and less commonly **Bidens pilosa* var. *pilosa*. Coolabah Woodland was characterised by a species-rich ground layer, and graded into grasslands of *Thellungia advena*, *Dichanthium sericeum* and *Panicum decompositum* where the *Eucalyptus coolabah* tree layer was greatly reduced. Black to grey vertosols were closely associated with this unit, and like Flooded Coolabah, were soils capable of retaining moisture for long periods (Burgess 2003). However, this floristic group displayed much greater species richness than Flooded Coolabah, and was probably inundated by floodwaters for briefer periods.

Mixed Alluvial Woodland (4 sites)

Species richness: 29–40 Mean species/site: 32.5
Mean weed species/site: 3 Mean total weed cover/site: 5.5% FPC

This unit was often dominated by *Eucalyptus populnea* or *E. coolabah*. Occasionally *E. melanophloia* dominated. A species-rich ground layer of grasses and forbs was typical, commonly *Brunoniella triandra, Chloris divaricata, Enneapogon polyphyllus, Enteropogon aciculoris, Galactia tenuifolio, Grewia latifolia, *Opuntia stricta, Sporobolus caroli, Themeda triandra, Rhynchosio minima* var. *minima* and *Eremophila debilis.* Mixed Alluvial Woodland appeared much less subject to active riverine processes such as flooding, occurring on stable alluvial plains. Soils were coarse-textured with a sandy surface layer, and chromosols with occasional vertosols were predominant. These were likely to remain wet for shorter periods after heavy rainfall compared to Flooded Coolabah and Coolabah Woodland.

Riparian Forest (7 sites)

Species richness: 14–36 Mean species/site: 24.8
Mean weed species/site: 3.7 Mean total weed cover/site: 16.0 % FPC

Riparian Forest contained an upper stratum of *Eucalyptus camoldulensis* and *Eucalyptus cooloboh* or occasionally *Eucalyptus tereticornis*, with a dense ground layer of *Eustrephus latifolius, Arundinella nepalensis, Lomondra longifolia, *Megathyrsus moximus* var. *pubiglumis* and less frequently, **Sida spinosa, *Senna barclayana, Ficus opposito, Chionachne cyathopoda, Chrysopogon filipes* and *Eulolia aurea.* Riparian Forest was associated with active levees and channel benches, subject to frequent inundation and high velocity flood wash. Predominant soils were grey vertosols underneath thin chromosols or kandosols. This group was discerned at a high (>0.80) dissimilarity level, as further subdivisions did not add significantly to the analysis. Despite locally heavy stock trampling and other pressures, this unit had a relatively low weed presence.

Broad Group 2 included three unusual sites along with mixed woodlands on sandy alluvium

Weeping Ti-tree *Melaleuca leucadendra* Forest (1 site)

Species richness: 23 Weed species: 4 Total weed cover: < 1 % FPC

Weeping Ti-tree Forest was dominated by *Melaleuca leucadendra* with emergent *Eucalyptus camaldulensis.* The ground and shrub layer were characterised by *Cynodon dactylon, *Cryptostegia grondifolia. Glinus oppositifolius* and *Ponicum laevinode.* This unit appeared subject to regular inundation, and occurred on deep sands within active river channels. Weeping Ti-tree Forest contained a number of species of open and disturbed areas, consistent with its location in areas subject to constant flooding. *Melaleuco leucadendra* appeared able to colonise broad spits of coarse river sands within the lowest reaches of the main Dawson River channel, an ecological role taken by *Meloleuca linariifolia* further south.

Disturbed Blue gum *Eucalyptus tereticornis* (1 site)

Species richness: 6 Weed species: 2 Total weed cover: 80 % FPC

Disturbed Blue gum contained a tree layer of *Eucalyptus tereticornis.* A dense ground layer of **Urochloa mosombicensis* dominated this site, to the exclusion of other ground layer species. Disturbed Blue gum appeared to undergo infrequent flooding, and occurred on grey loams or sands over vertosols. Prior to infestation by *U. mosambicensis*, the floristics of this community probably resembled the Blue Gum Depression site.

Blue gum *Eucalyptus tereticornis* Depression (1 site)

Species richness: 17 Weed species: 1 Total weed cover: 0.5 % FPC

This association formed a woodland of *Eucalyptus tereticornis*, with a ground layer of grasses such as *Bothriochloa ewartiana, Leptochloa decipiens* and *Sporobolus caroli*, and forbs typical of wet depressions, such as *Marsilea hirsuta, Alternanthera denticulata* and *Centipeda minima.* Surprisingly, there were few sedges present, apart from *Cyperus bifox.* Weeds were generally absent, apart from a minor presence of **Gomphrena celosioides.*

Sandy Alluvial Woodland (5 sites)

Species richness: 15–27 Species richness/site: 19.4
Mean weed species/site: 2.4 Mean total weed cover: 33.5 % FPC

This floristic group contained a tree layer of *Corymbia tessellaris* or *Eucalyptus coolaboh* or *Eucalyptus populnea*, with *Eucalyptus tereticornis* consistently subdominant, and a ground layer of *Bothriochloa ewartiana, Plectranthus parviflorus, *Melinis repens*, and **Cenchrus ciliaris.* The latter two species frequently dominated the ground layer. Less frequently *Oxalis perennans, Eucalyptus melanophloia, Wahlenbergio communis, Cyonthillium cinereum* and **Gomphrena celosioides* occurred. Sandy Alluvial Woodland was located on coarse or sandy textured soils, typically deep chromosols, dermosols and sodosols, and was probably seldom flooded except for run-on. These soils appeared to be free draining. Sandy Alluvial Woodland occurred on channel benches or narrow flats within upper tributaries.

Broad group 3 included open forests of Brigalow or Blackbutt or semievergreen thicket

Brigalow *Acacia harpophylla* Forest (3 sites)

Species richness: 20–26 species Mean species/site: 23
Mean weed species/site: 1.3 Mean total weed cover: < 1 % FPC

This group was located on the clay plains adjacent to the alluvial floodplain. It formed an open forest of *Acocia harpophylla* frequently with *Eucalyptus cambageano*, and was characterised by a dense, well-developed shrub layer of *Geijero parviflora, Carissa ovata and Capparis lasiantha*, with occasional vines such as *Cissus opoca.* A sparse ground layer of *Cyperus grocilis* and *Paspalidium caespitosum* was always present. Soils were dark brown sodosols. While probably seldom flooded, the soils of this floristic unit can remain wet for long periods, due to their location on very heavy clays, and by water ponding within gilgai microrelief (Burgess 2003).

Semi-evergreen thicket (1 site)

Species richness: 22 species Weed species: 3 Weed species cover: 40 % FPC

Semi-evergreen thicket occurred close to the Dawson River channel, on or near steep alluvial slopes. Typical species include a mixed tree layer of *Acacia fosciculifera, Geijera porvifloro, Diospyros humilis, Diospyros geminata, Ehretia membranifolia, Denhamia oleoster*, and a sparse ground layer of *Enteropogon unispiceus.* Exotic species were prominent in the groundlayer, particularly **Megathyrsus maximus vor. pubiglumis*, and **Bryophyllum delogoense.* Unlike the previous association this association is dominated by vine thicket species, and lacks emergent *Eucolyptus* or *Acacia* spp. Semievergreen thicket is probably only occasionally flooded, and appeared protected from drying winds and fire by the presence of steep alluvial banks in close proximity to moist riverbeds and channels.

Discussion

Ecological factors underlying floristic patterns

The study area contains some of the most extensive, near-coastal examples of *Eucalyptus coolabah* and *Eucalyptus camaldulensis*-dominated communities in eastern Australia, occurring some 80 km west of the coastline near Rockhampton. These are unusual, mesic examples of plains communities more commonly associated with the rivers of central and southwestern Queensland e.g. Boyland (1984), Neldner (1984). This is reinforced by the presence of genera more typical of coastal eastern Queensland, such as *Livistona, Ficus, Imperata, Chionachne* and *Arundinella*, as well as rainforest taxa such as *Trophis scandens* and *Melia azedarach.*

Flooding is likely to be fundamental to ecological processes in most of the communities identified in this study. The establishment of *Eucalyptus camaldulensis* is dependent on availability of soil moisture, and is thought to occur through infrequent major flood events, leading to even-aged stands (Stefano 2002). Seedling recruitment of *Eucalyptus coolabah* is also thought to be reliant on heavy rainfall events, as confirmed elsewhere in southern Australia (Roberts 1993). Locally, stands of both species, as well as *Eucalyptus tereticornis*, are known to have arisen from recent historical flood events (Eberhard 1999), particularly from the 1950s and 1970s.

Flood frequencies together with soil drainage properties appear to be important determinants of floristic variation across the study area. For example, *Eucalyptus coolabah* dominated communities were associated with heavy clays subject to one in 10 to 20 year flood intervals (Eberhard 1999, Burgess 2003), while *Acacia harpophylla* or semi-evergreen thickets were associated with similar soils mostly free from flood influence, but able to remain moist for extended periods (Fig. 3). Riparian forests were intimately associated with primary river channels and one in two to five year flood intervals (Eberhard 1999, Burgess 2003). *Eucalyptus tereticornis/Corymbia tessellaris*-dominated communities were associated with well-drained sandy loams derived from quartz sandstones, often within narrow tributaries subject to very infrequent flood events.

The grassy woodlands in the study area supported the greatest richness of vascular plant species. Indeed, the most species rich site sampled from this study approached a *Dichanthium sericeum* grassland in structure and floristic composition. This site was classified within Coolabah Woodland, which exhibited the highest mean species richness/site of all the communities sampled in this study.

Conversely, *Eucalyptus coolabah* woodland sites with 'swampy' ground layers, indicated by presence of *Muehlenbeckia florulenta*, *Marsilea drummondii*, *Alternanthera* spp., *Eriochloa* spp. or *Eleocharis* spp. (Flooded Coolabah), were associated with lower species richness/site within the study area. Such species appear to be further examples of water-enrichment specialists or tolerators (McIntyre & Martin 2002). Both floristic groups occurred on similar soil types, and varied only in their likelihood and period of inundation. Thus *Eucalyptus coolabah* communities exhibited high levels of variation in native species richness, and environments prone to prolonged wet periods were associated with fewer species.

Flooded Coolabah can be considered a type of wooded wetland, which graded into treeless sedgeland or grassland associations dominated by *Cyperus* spp., *Eleocharis* spp., *Marsilea* spp. or *Paspalum distichum*. These ephemeral floodplain wetlands were not systematically sampled, but have clear floristic affinity, were widespread across the study area, and occurred on similar land elements and soil types as Coolabah Woodland. Blue gum Depression can be considered the analogous floristic association within lighter textured soils, with a groundlayer that also includes water-enrichment specialists (McIntyre & Martin 2002).

Mixed Alluvial Woodland was characterised by a set of groundlayer species considered disturbance intolerant, or intolerant of artificial nutrient enrichment in the soil (McIntyre & Martin 2002). These species included *Brunoniella australis*, *Themeda triandra*, *Galactia tenuifolia* and *Eremophila debilis*. This confirms the choice of these sites as relatively undisturbed by severe grazing. Coolabah Woodland in contrast, had a dominance or presence of groundlayer species considered more typical of moderate levels of disturbance or grazing pressure, such as *Cyperus gracilis*, **Malvastrum americanum*, *Heteropogon contortus* and *Bothriochloa bladhii* var. *bladhii* (Grice & McIntyre 1995, McIntyre & Martin 2002).

This study recorded a general decrease in species richness in the ground layer of grassy woodlands from heavy clays to sandy alluvia, on non-riparian alluvial plains. The reasons for this are unclear, and appear not to be directly linked to grazing, given that at least two of the species (**Melinis repens* & *Themeda triandra*) observed distinctively within Sandy Alluvial Woodland are considered grazing intolerant (Grice & McIntyre 1995, Fensham & Holman 1998). It is possible that some exotic perennials more readily establish on sandier substrates or conversely, that fewer exotics tolerate the seasonally wet and heavy soils of *Eucalyptus coolabah* woodlands, as Cavaye (1991) observed for the exotic pasture species **Cenchrus ciliaris*.

Sites within the study area appear less species rich than similar grassy woodlands in southern and central Qld sampled by McIntyre and Martin (2001). This may be due to seasonally suboptimal sampling periods, or may reflect reduced species richness in a region with greater rainfall variability. Richness of species per floristic community is comparable to that recorded by Gosper et al. (2002) for the Darling Riverine Plains of NSW, and was sampled using quadrats of similar size.

Riparian Forest within the lower Dawson study area was characterised by a ground layer of very tall, woody-culmed native grasses such as *Arundinella nepalensis* or *Chionachne cyathopoda*, and less commonly *Leptochloa digitata* or *Eulalia aurea*. These grasses formed dense swards and dominated the ground layer, apparently excluding or suppressing some of the forbs and twiners more commonly observed in Coolabah Woodland.

Presence of exotic species

The studies and synthesis of Tothill and Gillies (1992) and Grice and McIntyre (1995) support our contention that sites sampled within this study contained perennial grasses typical of pastures subject to low grazing pressure (although see alternate viewpoint of use of increaser/decreaser as grazing indicator species by Vesk & Westoby 2001). The sites sampled indicate the condition of the least disturbed vegetation in the study area, and contrast strongly with the findings of Telfer (1995), whose study was not constrained by sampling within 'intact' sites. Despite this, our study showed a significant presence of exotic grasses in the two broad vegetation types of *E. camaldulensis* and *E. coolabah* forests and woodlands within the study area. Comparing this with the landscape descriptions of Speck et al. (1968), in which exotic plants are inconspicuous, suggests considerable changes in the abundance of exotic plants in the study area since the 1960s.

Sites with a high FPC cover of the introduced grasses **Urochloa mosambicensis*, **Megathyrsus maximus* var. *pubiglumis*, **Cenchrus ciliaris* and **Melinis repens* tended to be the poorest in species within this study. These observations from the lower Dawson River support the findings of Fairfax and Fensham (2000) and Franks (2002), that exotic grasses may reduce native species richness within the ground layer of grassy woodlands in Queensland.

Unlike McIntyre and Martin (2001), strictly riparian vegetation was not the most weed-infested in this study, though at a broad scale much of the vegetation sampled was 'riparian'. Other than gross mechanical disturbance or deliberate introduction of exotic pastures, the most likely factors favouring weed invasion in remnant vegetation in the study area appear to be heavy stock use of remnant woodlands/ forest close to permanent water (itself influenced by impoundment construction).

Grazing is known to be the dominant land-use in the study area (Telfer 1995). Heavy localised stock use of riparian lands appears likely to influence establishment of some exotic species within intact riparian vegetation. Other studies of *Eucalyptus camaldulensis* ecosystems in south-eastern Australia have suggested that ecological condition declined as grazing intensity increased (e.g. Jansen & Robertson 2001). However it should be noted that grazing can suppress the growth of some weeds in riparian woodlands in subcoastal Qld (such as the climbing *Macfadyena unguis-cati*) and the interaction between grazing and weed invasion is complex.

Eberhard (1999) recorded a greater proportion of understorey weeds present within the study area at riverine sites upstream of weirs compared to downstream locations, suggesting that proximity to an abundant water source may influence establishment of exotic species.

**Megathyrsus maximus* var. *pubiglumis* was the third most frequent ground stratum species and the most prevalent exotic species in this study, occurring in eleven of the thirty sites sampled. It is therefore important to consider the ecology of this species. The dense shade cast by the tree layer of some riparian forests and woodlands in the study area appeared to suit the establishment of **Megathyrsus maximus* var. *pubiglumis*, a result observed elsewhere in sub-coastal Queensland (Wilson & Wild 1990). This may account for its significant presence in Coolabah Woodland and Riparian Forest recorded in this study. The apparent paradox of shading actually increasing the competitive ability of **Megathyrsus maximus* var. *pubiglumis* is thought to be related to an increase in available soil nitrogen in a shaded microclimate (Wilson & Wild 1990), perhaps further exacerbated by **M. maximus*'s ability to fix nitrogen (Skerman & Riveros 1990). We speculate that this process interacts with localised disturbances such as heavy stock use of frontage lands close to permanent water (not necessarily grazing *per se*) favouring establishment of **Megathyrsus maximus* var. *pubiglumis*.

In some instances, grazing pressure alone may be correlated with an increase in exotic grasses. In their review, Grice and McIntyre (1995) suggested that the presence of **Urochloa mosambicensis* was associated with high grazing pressure. In this study, **Urochloa mosambicensis* was distinctive to Disturbed Blue Gum, although this site did not appear to have undergone unusually heavy grazing pressure at time of sampling.

Relationships between floristic communities, vegetation types and regional ecosystems

Regional ecosystems (REs) are primarily distinguished by the composition of the ecologically dominant stratum, usually the tree layer (Sattler & Williams 1999), as well as their associated geological parent materials. It is important to know how classification based on dominant strata relates to classification based on total, or even ground stratum floristics. The relationships between the floristic groups developed in this study are also inherently interesting. The total floristic ordination conducted in this study (Fig. 3) tended to group together sites representing the same RE. However, classification suggested several groups that contained more than one RE, and sites dominated by *Eucalyptus coolabah* were placed into several floristic groups (mostly without any sites from other REs), suggesting several subunits within RE 11.3.3 in the study area.

The floristic analysis suggested *Eucalyptus populnea*-dominated communities have affinity with some forms of *Eucalyptus coolabah* or *Eucalyptus tereticornis* grassy woodlands. Other field observations also showed this tendency, usually as an infrequent intermixing of these dominant trees between and within stands, particularly within channel benches and active levees. Burgess (2003) observed similar intergradation of tree species in riparian vegetation within the Isaac and Mackenzie Rivers. Other forms of *Eucalyptus coolabah*-dominated woodlands clearly graded into *Eucalyptus camaldulensis*-dominated riverine forest on levees. In this region and in several other extensive areas of central and inland Qld, *Eucalyptus coolabah* was a frequent subdominant tree in this broad community (e.g. Neldner 1984).

While some of this community variability appears related to significant local soil differences (McCarrol 1996), it seems clear that the delineation of natural floristic groups must remain imprecise, if based on dominant trees alone. Fensham

(1998) studied and compared vegetation and floristic patterns in grassy woodlands of the Darling Downs, and concluded that the presence of a dominant tree species did not always match floristic groupings. Gosper et al. (2002) found dominant canopy vegetation was a poor predictor of floristic assemblage in their analysis of floodplain vegetation of the Darling River Plains.

Acacia harpophylla and *Eucalyptus cambageana* -dominated communities appeared related to the semi-evergreen vine thicket sampled in this study, due to the large number of shrub species common to both associations. Partridge et al. (1994) also noted the presence of many shrubs common to these broad vegetation types. Occurring as dense structural formations, these units contained few weeds, except when occurring as isolates in paddocks of exotic sown pastures.

Given that Poaceae dominated the flora of the study area, was the analysis biased toward the presence/absence of dominant or subdominant perennial grasses? Re-examination of the communities defined does not suggest this. Firstly, an additional ordination of sites with all woody species removed produced similar community groupings for grassy woodlands, and did not separate them in further meaningful groups. Secondly, there were few floristic groups where there was a consistent dominance or presence of a grass species (mainly Flooded Coolabah and Riparian Forest). Coolabah Woodland (the most floristically rich group), did not have a single consistent dominant or subdominant grass, whereas within Sandy Alluvial Woodland there was a weak trend of dominance of **Cenchrus ciliaris*, **Melinis repens* or *Themeda triandra*. Mixed Alluvial Woodland showed a weak subdominant trend of *Chloris divaricata*. Thus communities cannot be discerned from the presence of dominant grasses alone. In fact within the 30 sites recorded, there were 26 different frequent grass species, underlining their variability within plant assemblages in the study area. Other authors have noted the high variability within the ground layer of perennial pasture within a single paddock (e.g. McDonald & Hodgkinson 1996). It appears that the single large quadrats used in this study did not adequately sample the full range of floristic variability within the groundlayer, and that smaller, more numerous quadrats would be required for this.

Speck et al. (1968) recognised broad recurring understorey assemblages as 'native pasture communities' in the Fitzroy–Dawson River region. The two most frequent types appropriate for the lower Dawson were 'eastern mid-height grass' occurring in grassy woodland on alluvia, and 'frontage grass' associated with riverine woodlands and forests. There is broad concurrence between the listed species of Speck et al. (1968) and this study.

More recently, Tothill and Gillies (1992) outlined the broad pasture communities of northern Australia, including the Dawson River study area. The groundlayer of most of the grassy woodlands within this study closely matched elements of the widespread Southern black speargrass community, specifically LPU 30 (Tothill & Gillies 1992), particularly Coolabah Woodland and Mixed Alluvial Woodland. On very heavy alluvial clays, the groundlayer of Coolabah Woodland approached Southern flooded Alluvial plains (LPU 74), a grassland unit (Tothill & Gillies 1992). The groundlayer of the Riparian Forest floristic assemblage appeared similar to that described for the Fringing tallgrass pastures of the rivers of the Eastern Kimberly, LPU 5 (Tothill & Gillies 1992), although apparently undescribed for mid-eastern Queensland.

Conclusions

Flooding frequency, duration, and soil texture appear to be major determinants of floristics within the study area. Regional Ecosystems (Sattler & Williams 1999) formed reasonable associations within floristic composition but some contained several clear 'within RE' types.

The remnant natural vegetation of the study area remains in a mostly intact condition, with localised infestations of exotic weed grasses. These were correlated with reduced native species richness, and their establishment is possibly facilitated by disturbance associated with intensive stock use of areas close to permanent water. **Megathyrsus maximus* var. *pubiglumis* was associated with denser vegetation of clay soils, while **Cenchrus ciliaris* was more common in woodlands with sandy-textured soils.

Speck et al. (1968) did not record or otherwise note any local occurrence or dominance of land units by exotic plants. These were readily observed in this study, and have been recorded widely along the lower Dawson (Telfer 1995). It seems likely many environmental and agricultural weeds have established and spread since the 1960s.

Given the relationships between flood frequency and floristics, it would be prudent to monitor floodplain vegetation and floristics across future major river modifications within the lower Dawson system. The findings and sampling sites of this study provide a basis and context for this.

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Appendix 1. Vascular plant species recorded from the Lower Dawson River study area. Nomenclature according to Henderson (2002).

* denotes exotic species
R = rare in QLD (Under the schedules of the Nature Conservation Act 1992)

ACANTHACEAE

Brunoniella australis
Dipteracanthus australasicus subsp. *australasicus*
Pseuderanthemum variabile
Rostellularia adscendens

ADIANTACEAE

Cheilanthes sieberi

AIZOACEAE

Tetragonia tetragonioides
Zaleya galericulata subsp. *galericulata*

AMARANTHACEAE

Achyranthes aspera
Alternanthera denticulata
Alternanthera nana
Alternanthera nodiflora
Amaranthus interruptus
**Gomphrena celosioides*
Nyssanthes diffusa

APOCYNACEAE

Alstonia constricta
Carissa ovata
Parsonsia eucalyptophylla
Parsonsia straminea

ARACEAE

**Pistia stratiotes*

ARECACEAE

Livistona nitida **R**

ASCLEPIADACEAE

**Cryptostegia grandiflora*
Marsdenia viridiflora

ASTERACEAE

**Ageratum houstonianum*
**Baccharis halimifolia*
**Bidens pilosa*
Calotis cuneata
Cassinia laevis
Centipeda minima var. *minima*
Chrysocephalum apiculatum
Cyanthillium cinereum
**Emilia sonchifolia*
Ozothamnus apiculatum
**Parthenium hysterophorus*
Pterocaulon redolens
Senecio lautus subsp. *dissectifolius*
**Sonchus oleraceus*
Vittadinia dissecta
Vittadinia sulcata
**Xanthium pungens*

AZOLLACEAE

Azolla pinnata

BRASSICACEAE

Rorippa eustylis

BORAGINACEAE

Ehretia membranifolia
**Heliotropium indicum*

CACTACEAE

**Opuntia stricta* var. *stricta*
**Opuntia tomentosa*

CAESALPINIACEAE

Cassia tomentella
Lysiphyllum carronii
Lysiphyllum hookeri
**Parkinsonia aculeata*
Senna barclayana
Senna artemisioides subsp. *zygophylla*

CAMPANULACEAE

Wahlenbergia gracilis

CAPPARACEAE

Apophyllum anomalum
Capparis sp.
Capparis canescens
Capparis lasiantha

CASUARINACEAE

Casuarina cunninghamiana
Casuarina cristata

CELASTRACEAE

Denhamia oleaster
Elaeodendron australis var. *integrifolium*
Maytenus bilocularis
Maytenus cunninghamii

CERATOPHYLLACEAE

Ceratophyllum demersum

CHENOPODIACEAE

Atriplex muelleri
Einadia hastata
Einadia nutans var. *linifolia*
Enchylaena tomentosa
Maireana microphylla
Salsola kali
Sclerolaena anisacanthoides
Sclerolaena birchii
Sclerolaena muricata
Sclerolaena tetracuspis

COMBRETACEAE

Terminalia oblongata

COMMELINACEAE

Commelina ensifolia

CONVOLVULACEAE

Convolvulus arvensis
Evolvulus alsinoides

CRASSULACEAE

**Bryophyllum delagoense*

CUPRESSACEAE

Callitris glaucophylla

CYPERACEAE

Carex rhytidocarpa
Cyperus bifax
Cyperus bulbosus
Cyperus concinnus
Cyperus curvistylis
Cyperus difformis
Cyperus distans
Cyperus exaltatus
Cyperus fulvus
Cyperus gracilis
Cyperus javanicus
**Cyperus tuberosus*
Cyperus victoriensis
Eleocharis acuta
Eleocharis plana
Eleocharis sphacelata
Fimbristylis dichotoma
Scleria mackaviensis

DILLENIACEAE

Hibbertia vestita

EBENACEAE

Diospyros geminata
Diospyros humilis

EUPHORBIACEAE

Acalypha eremorum
Chamaesyce drummondii
Chamaesyce psammogeton
Excoecaria dallachyana
Petalostigma pubescens

FABACEAE

**Aeschynomene indica*
**Cajanus cajan*
Crotalaria juncea
Crotalaria mitchellii
**Crotalaria montana*
Galactia tenuiflora var. *lucida*
Glycine tabacina
Glycine tomentella
Indigofera pratensis
Rhynchosia minima
Sesbania cannabina
Vigna vexillata

HALORAGACEAE

Haloragis aspera

HYDROCHARITACEAE

Ottelia ovalifolia

JUNCACEAE

Juncus polyanthemus
Juncus usitatus

JUNCAGINACEAE

Triglochin dubium

LAMIACEAE

Basilicum polystachyon
Plectranthus parviflorus

LEMNACEAE

Lemna aequinoctialis
Lemna sp.

LORANTHACEAE

Amyema quandang

MALVACEAE

Abutilon asiaticum var. *australiense*
Abutilon fraseri
Abutilon oxycarpum
**Malvastrum americanum*
Sida cordifolia
**Sida rhombifolia*
**Sida spinosa*
Sida subspicata
Sida trichopoda

MARSILEACEAE

Marsilea drummondii
Marsilea mutica

MELIACEAE

Melia azedarach
Owenia acidula
Owenia venosa

MENYANTHACEAE

Nymphoides indica

MIMOSACEAE

Acacia excelsa
**Acacia farnesiana*
Acacia fasciculifera
Acacia harpophylla
Acacia oswaldii
Acacia rhodoxylon
Acacia salicina
Acacia stenophylla
Archidendropsis basaltica
**Mimosa pudica*
Neptunia gracilis

MORACEAE

Ficus opposita
Trophis scandens

MYOPORACEAE

Eremophila debilis
Eremophila maculata
Eremophila mitchellii
Myoporum montanum

MYRTACEAE

Angophora floribunda
Angophora leiocarpa
Callistemon viminalis
Corymbia clarksoniana
Corymbia dallachiana
Corymbia tessellaris
Eucalyptus camaldulensis
Eucalyptus cambageana
Eucalyptus coolabah
Eucalyptus crebra
Eucalyptus melanophloia
Eucalyptus moluccana
Eucalyptus populnea
Eucalyptus tereticornis
Eucalyptus thozetiana
Lophostemon suaveolens
Melaleuca bracteata
Melaleuca leucadendra
Melaleuca linariifolia var. *trichostachya*

NELUMBONACEAE

Nelumbo nucifera

NYCTAGINACEAE

Boerhavia dominii
Boerhavia sp. (Bargara L. Pedley 5382)

NYMPHAEACEAE

Nymphaea gigantea

OLEACEAE

Jasminum didymum subsp. _punctatum_

ONAGRACEAE

Ludwigia octovalvis
*_Ludwigia peploides_ var. _montevidensis_

ORCHIDACEAE

Cymbidium canaliculatum

OXALIDACEAE

Oxalis perennans

PAPAVERACEAE

*_Argemone ochroleuca_

PASSIFLORACEAE

*_Passiflora foetida_ var. _foetida_
*_Passiflora suberosa_

PHORMIACEAE

Dianella caerulea

PITTOSPORACEAE

Bursaria incana
Pittosporum spinescens

POACEAE

Aristida benthamii
Aristida calycina
Aristida gracilipes
Aristida holathera var. _holathera_
Aristida jerichoensis
Aristida lignosa
Aristida longicollis
Aristida personata
Aristida ramosa
Arundinella nepalensis
Bothriochloa bladhii subsp. _bladhii_
Bothriochloa decipiens
Bothriochloa erianthoides
Bothriochloa ewartiana
Brachiaria gilesii
Brachyachne tenella
*_Cenchrus ciliaris_
Chionachne cyathopoda
Chloris divaricata
*_Chloris gayana_
Chloris truncata
Chloris ventricosa
*_Chloris virgata_
Chrysopogon fallax
Chrysopogon filipes
Cymbopogon queenslandicus
Cymbopogon refractus
Cynodon dactylon
*_Dichanthium annulatum_
Dichanthium sericeum subsp. _humilius_
Dichanthium sericeum subsp. _sericeum_
Digitaria brownii
*_Echinochloa colona_
*_Echinochloa crus-galli_
*_Echinochloa polystachya_
Enneapogon cylindricus
Enneapogon lindleyanus
Enneapogon polyphyllus
Enteropogon acicularis
Enteropogon ramosus
Eragrostis elongata
Eragrostis lacunaria
Eragrostis leptocarpa
Eragrostis parviflora
Eragrostis sororia
Eragrostis tenellula
Eriochloa sp.
Eriochloa crebra
Eriochloa procera
Eriochloa pseudoacrotricha
Eulalia aurea
Heteropogon contortus
*_Hymenachne amplexicaule_
Imperata cylindrica
Iseilema vaginiflorum
Leptochloa decipiens
Leptochloa digitata
Leptochloa fusca
*_Melinis repens_
*_Megathyrsus maximus_ var. _pubiglumis_
Panicum buncei
Panicum decompositum
Panicum effusum var. _effusum_
Panicum queenslandicum
Paspalidium caespitosum
Paspalidium criniforme
Paspalidium distans
Paspalidium gracile
Paspalidium jubiflorum
*_Paspalum_ sp.
Perotis rara
Setaria sp.
Sporobolus caroli
Sporobolus contiguus
Sporobolus creber
Sporobolus mitchellii
Sporobolus scabridus
Thellungia advena
Themeda triandra

POLYGONACEAE

Muehlenbeckia florulenta
Persicaria decipiens
Persicaria hydropiper
*_Persicaria lapathifolia_
Persicaria orientalis

PONTEDERIACEAE

Monochoria cyanea

PORTULACACEAE

Portulaca oleracea
Portulaca pilosa

POTAMOGETONACEAE

Potamogeton tricarinatus

PROTEACEAE

Grevillea striata

RHAMNACEAE

Alphitonia excelsa
Ventilago viminalis

RUBIACEAE

Canthium odoratum
Canthium oleifolium
Spermacoce multicaulis

RUTACEAE

Citrus glauca
Geijera parviflora

SALVINIACEAE

**Salvinia molesta*

SANTALACEAE

Santalum lanceolatum

SAPINDACEAE

Alectryon diversifolius
Alectryon oleifolius
Atalaya hemiglauca
Atalaya salicifolia
**Cardiospermum halicacabum* var. *halicacabum*
Cupaniopsis anacardioides
Elattostachys xylocarpa

SAPOTACEAE

Pouteria cotinifolia

SCROPHULARIACEAE

Limnophila aromatica
**Scoparia dulcis*

SMILACACEAE

Eustrephus latifolius

SOLANACEAE

Solanum semiarmatum

STERCULIACEAE

Brachychiton australis
Brachychiton populneus
Brachychiton rupestris
Melhania oblongifolia
**Melochia pyramidata*

TILIACEAE

Grewia latifolia

TYPHACEAE

Typha orientalis

VERBENACEAE

**Phyla canescens*
**Verbena aristigera*
**Verbena bonariensis*
**Verbena litoralis*
**Verbena officinalis*

VITACEAE

Cissus opaca

XANTHORRHOEACEAE

Lomandra longifolia

ZYGOPHYLLACEAE

Tribulus micrococcus
Zygophyllum apiculatum

The importance of seasonality in the timing of flora surveys in the South and Central Western Slopes of New South Wales

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Abstract: Semi-permanent quadrats, located in the South and Central Western Slopes botanical regions of New South Wales, were assessed to indicate suitable periods of the year to conduct surveys of botanical diversity. The quadrats were located in woodland communities with a generally herbaceous understorey, and subject to a wide range of domestic stock grazing intensities. In the mid to western South Western Slopes (SWS) the greatest number of species was generally recorded in an October survey. The main exception was in degraded areas (low species diversity, high proportion of annual weed species), where similar results were recorded in September and October. In the cooler and wetter eastern SWS a relatively high proportion of species were recorded in October to early December surveys. However, when compared to species totals compiled from multiple assessments in all seasons, or from August to November, a single optimal survey usually recorded only 60–75% of the plant species at a site. Surveys in mid to late summer, autumn and early winter usually recorded less than 50% of the plant species present. The results reflect the prevailing Mediterranean-type climate, and that the ground layer vegetation (primarily comprised of annuals and herbaceous perennials) dominates the species diversity.

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Introduction

Vegetation and flora surveys to assess plant species diversity can involve many variables, including whether to use quadrats or random searches, expertise of personnel, plot size, number of plots, time of survey and preceding weather conditions (Kirby et al. 1986, Scott & Hallam 2002, Barnett & Stohlgren 2003, Kercher et al. 2003, Kéry & Gregg 2003). When and how often to sample often depend on personnel availability, budget constraints and an appreciation of the seasonality of the flora under investigation (Ristau et al. 2001, Tremblay & Larocque 2001). Understanding the seasonality of vegetation is important both when designing effective sampling schemes, and when interpreting the diversity reported in previous assessments. The South Western Slopes (SWS) botanical region of New South Wales (NSW) experiences a Mediterranean-type climate (cool, moist winters and hot, dry summers). At Wagga Wagga (average annual rainfall 583 mm), average monthly precipitation is relatively constant through the year, but there is a high degree of variability on a monthly basis, especially from December to May, as indicated by the differences between mean and median rainfall and a variability index (Table 1). Only in June and July does average precipitation exceed evaporation, while in December, January and February average evaporation is at least 6 times the average rainfall (Table 1). A similar pattern has been recorded for much of the SWS (Moore 1953).

The distinct seasonal differences in the ratio of rainfall to evaporation are reflected in the proportion of growth forms in the vegetation. Moore (1953), in an assessment of the South Eastern Riverina, found the life-form spectrum was dominated by cryptophytes and hemicryptophytes (usually herbaceous perennials) and therophytes (annuals). Burrows (1999) found that, of 658 taxa recorded in areas of remnant vegetation in the SWS, 31% were annuals or biennials, 45% perennial herbs and 24% trees or shrubs. Trees and shrubs may be recognised in any season, although identification to species level may be difficult without flowers and/or fruits. In contrast herbaceous species (annuals and herbaceous perennials) may not be recognisable for extended periods of the year. During summer the annuals are present as seeds and the majority of the herbaceous perennials are present, primarily as below-ground bulbs, corms and other specialised rootstocks. Only a few herbaceous perennials remain in leaf over summer e.g. *Lomandra* and *Dianella* species. Almost all of the rare or threatened species recorded for the SWS are perennial herbs or annuals (Burrows 1998).

Methods for conducting vegetation surveys have been extensively developed (Ristau et al. 2001, Barnett & Stohlgren 2003). For example, the NSW National Parks & Wildlife Service (now part of the NSW Department of Environment & Conservation) provide detailed survey forms, to be used on a state-wide basis. However, no guidelines or stipulations are specified as to the timing of surveys. It is possible that surveys might be conducted at less than optimal times of the year for reasons such as a lack of appreciation of species' growth patterns, to purposely avoid finding vulnerable or endangered species, or to expend funds by the end of the financial year. The author and other environmental consultants in the region are disturbed by the continuing requests for surveys from mid summer to mid winter. The aim of compiling this seasonality data is to suggest suitable

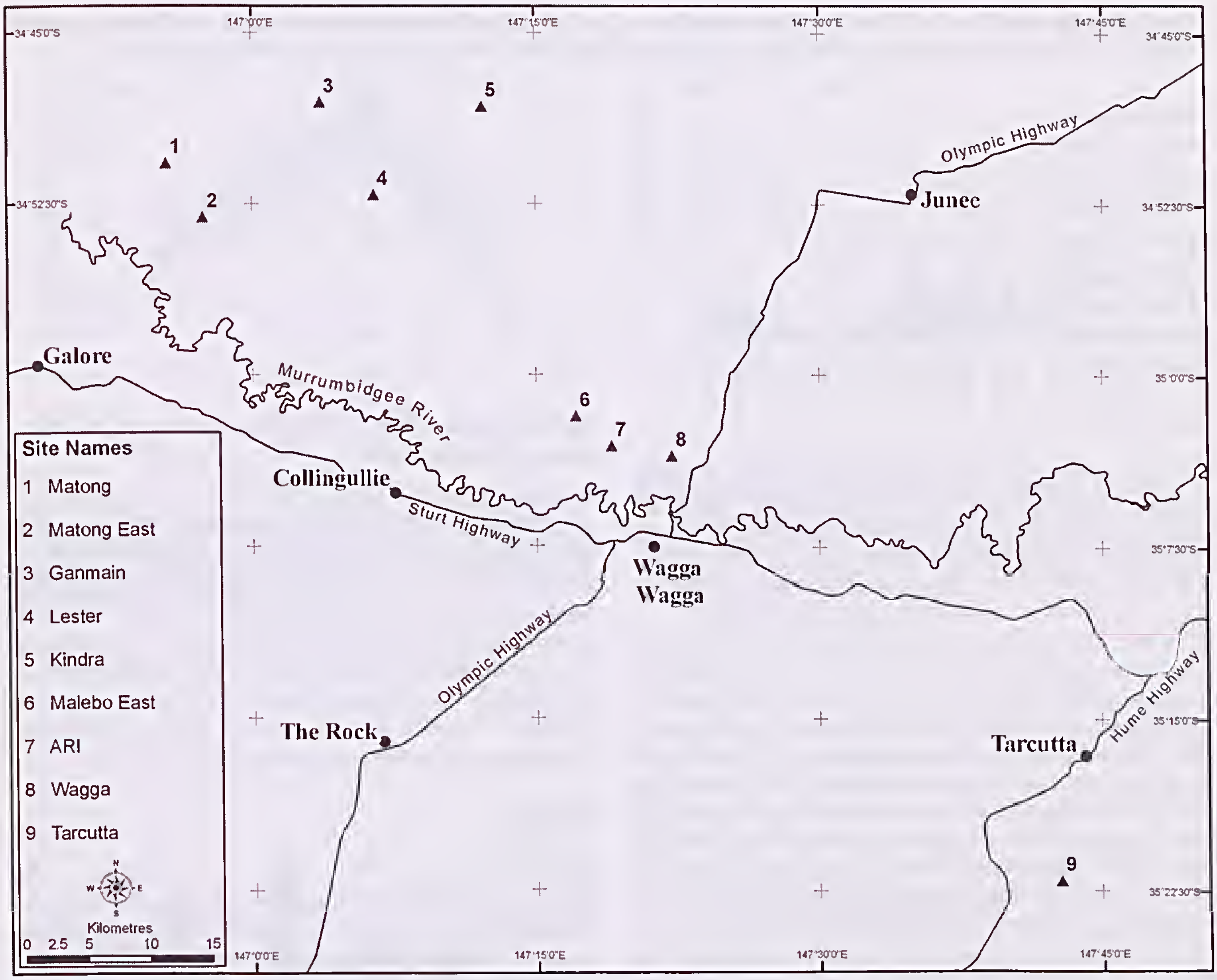

Fig. 1. The location of the nine study sites in the SWS botanical region.

sampling times and, perhaps even more importantly, to quantify what percentage of the flora might be missed at sub-optimal times.

Materials and methods

Data for this assessment of seasonality was from four separate surveys conducted between 1996 and 2005. Three were in the SWS botanical region and one was in the CWS botanical region of NSW. All four were in the NSW South Western Slopes (IBRA) biogeographical region. Figure 1 shows the location of the SWS botanical region study sites. Species were recorded as present on the basis of vegetative, reproductive or dead material. Each quadrat was assessed 'blind' i.e. without reference to previous survey records, and the same assessor was involved in the assessment of each quadrat, and for all the species identifications. For the 2001–2003 assessments a species' developmental stage was also recorded (vegetative, flower buds present, flowering, fruiting, dead). Average annual rainfall varies from c. 450 mm around Matong to 800–850 mm in the Tarcutta Hills region (Fig. 1). Various monthly climatic averages for Wagga Wagga and Wyalong are given in Table 1.

White Cypress Pine woodlands

During 1996, seven sites, 10–50 km NW of Wagga Wagga with a *Callitris glaucophylla* overstorey, were assessed (Fig. 1). These sites had three levels of domestic stock grazing intensity: low (Kindra State Forest [SF] and Ganmain SF), moderate (Lester SF and Matong SF, and a private property on the eastern side of Malebo Range) and high (a property on the eastern border of Matong SF, and a paddock managed by the NSW Agricultural Research Institute [ARI] at Wagga Wagga). At each site 15 randomly located 10 × 10 m semi-permanent quadrats were established; each quadrat was assessed 4 times, at roughly monthly intervals (August, September, October, November). Rainfall for Wagga Wagga was average or above average for June, July, August, September and November 1996 and 69% of average in October.

Table 1. Average monthly rainfall (mm), median rainfall (mm), rainfall variability (decile 9 minus decile 1 then divided by decile 5) and average monthly evaporation (mm) figures for Wagga Wagga 1941–2002 and Wyalong Post Office 1895–2001.

	J	F	M	A	M	J	J	A	S	O	N	D	Total
Wagga Wagga													
Average rainfall	41	40	43	44	54	50	56	53	51	62	44	45	583
Median rainfall	31	26	26	29	41	47	55	55	48	51	35	34	
Rainfall variability	2.7	3.4	4.2	2.7	2.8	1.7	1.4	1.5	1.5	2.0	2.2	2.6	
Average evaporation	307	255	211	117	62	36	37	59	84	146	210	295	1819
West Wyalong													
Average rainfall	45	36	38	37	41	42	42	40	37	47	37	43	485
Median rainfall	28	21	23	27	32	36	39	41	30	38	31	31	
Rainfall variability	3.8	4.3	4.3	3.0	2.9	1.8	1.7	1.3	2.3	2.3	2.4	3.3	

Lake Cowal

On the edge of Lake Cowal, c. 35 km NW of West Wyalong in the CWS, forty-one 10 × 10 m quadrats were established within a 3 × 5 km site on private property during 1997. Seven quadrats were located on the treeless, seasonally inundated, lake bed, while the remainder were in cleared paddocks or open woodland (remnant overstorey species of *Acacia pendula, Casuarina cristata, Callitris glaucophylla, Eucalyptus camaldulensis, Eucalyptus dwyeri, Eucalyptus populnea* and *Geijera parviflora*). All areas were grazed by domestic stock, with intensity ranging from moderate to high. The quadrats were assessed on September 23/24 and again three and half weeks later on October 18/19. At the first survey the surface soil was moist and the gilgai depressions were almost full of water, while by the second survey the upper soil layers were dry and the smaller gilgais empty. At the Wyalong Post Office c. 60 mm of rainfall was recorded in 6 rain days in the three weeks before the first survey, while 21 mm of rain was recorded on one rain day between the surveys. Rainfall for West Wyalong was average or above average in May, June and August 1997 and 55% of average in July.

Charles Sturt University (Wagga Wagga Campus)

During 2001, five 10 × 10 m quadrats were established in a straight line, with 10 m between each quadrat, on a lightly grazed paddock with a *Eucalyptus melliodora* overstorey on the Wagga Wagga campus of CSU. The quadrats were assessed 18 times between July 2001 and November 2002, and twice in October 2003. The 2002 growth period (April–October) was the sixth driest since records began in 1898 (Anon. 2003). Monthly rainfall data for the main study period is given in Figure 3.

Tarcutta Hills Reserve

During 2003 six 10 × 10 m quadrats were established in the Australian Bush Heritage Fund's Tarcutta Hills Reserve. Three quadrats were on ridges with an overstorey of *Eucalyptus macrorhyncha, Eucalyptus rossii* and *Eucalyptus sideroxylon* and three quadrats were in the intervening gully areas with an overstorey of *Eucalyptus goniocalyx, Eucalyptus macrorhyncha* and *Eucalyptus polyanthemos*. The quadrats were surveyed at roughly monthly intervals from November 2003 to January 2005. Monthly rainfall data for the study period is given in Figure 4.

Combining all the surveys the study is based on 670 assessments of 157 quadrats. The number of plant species in each quadrat at each assessment was counted. The total number of plant species recorded in a quadrat was determined for the full period for which assessments were made. For each assessment the percentage of species recorded, in relation to the total number of species found in that quadrat over all assessments, was calculated. As most quadrats at a site produced a similar seasonal trend (e.g. Fig. 2) data was averaged across quadrats at a site (Table 4, Figs 3, 4).

Results

Growth form

The proportion of growth forms (annual/biennial, herbaceous perennial, shrub, tree) was calculated for the plant species recorded at each of the study sites (Table 2). At all sites shrubs and trees constituted fewer than 8% of the species recorded, except at Ganmain and Tarcutta Hills, where they constituted between 12 and 17% (Table 2). The annuals/biennials and perennial herbs made up, on average, 53% and 40% of the recorded species respectively (Table 2). Most of the annuals (average 69%) were introduced species, and almost all of the perennial herbs (average 90%) were native (Table 2). Almost all annuals were dead and undetectable by early to mid summer (e.g. see Fig. 5). The majority of the herbaceous perennials had mesophytic leaves and the plants died back to underground bulbs, corms, tubers and other rootstocks during late spring to early summer. Thus, given the high proportion of annuals and herbaceous perennials in the surveyed floras, the mesophytic leaf types of these species and Mediterranean-type climate, it could be expected that a high percentage of species would not be recordable during summer and autumn.

Seasonality

The 1996 and 2001/2002 studies in the mid to western SWS assessments in October recorded the highest number and percentages of species (Tables 3, 4, Fig. 3); however in the more heavily grazed sites (Matong E and ARI), the total number of species was low, a high proportion of these

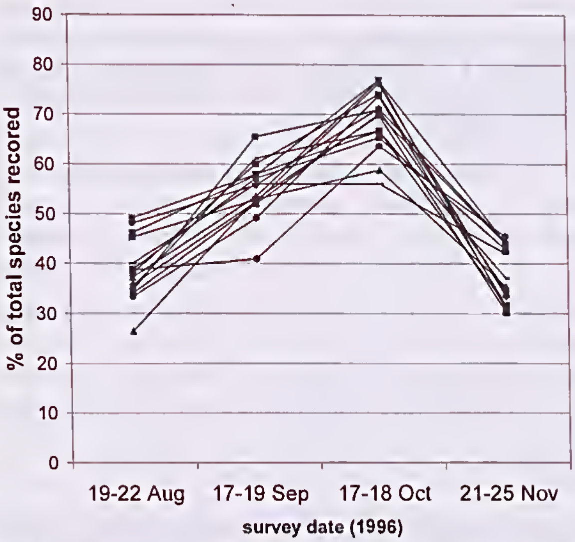

Fig. 2. The percentage of total species recorded over 4 months in 1996, in each of 15, 10 × 10 m quadrats, at Lester State Forest. The figure indicates the percentage of the quadrat total recorded at each assessment for each of the 15 quadrats.

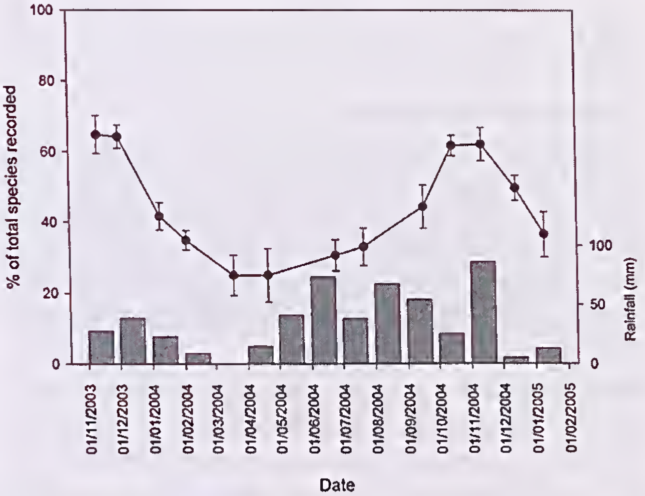

Fig. 4. The percentage of total species recorded over 15 months in 2003–2005, averaged over 6, 10 × 10 m quadrats, at Tarcutta Hills Reserve. The figure indicates the percentage of the mean quadrat total (95% CI) recorded at each sampling period. The monthly rainfall data is for Wagga Wagga.

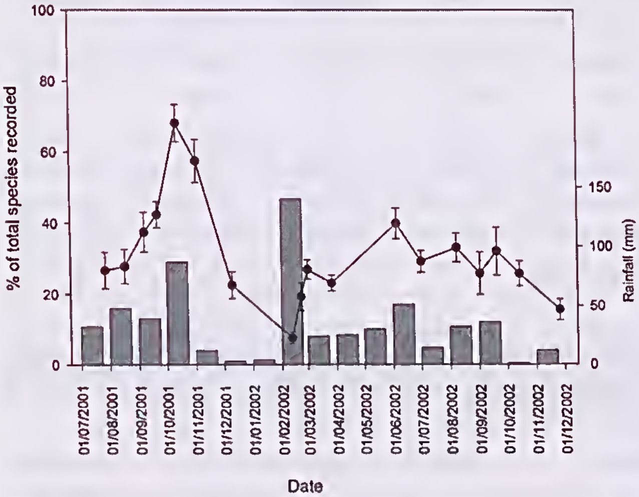

Fig. 3. The percentage of total species recorded over 17 months in 2001 and 2002, averaged over 5, 10 × 10 m quadrats, at Charles Sturt University. The figure indicates the percentage of the mean quadrat total (95% CI) recorded at each sampling period. The monthly rainfall data is for Wagga Wagga.

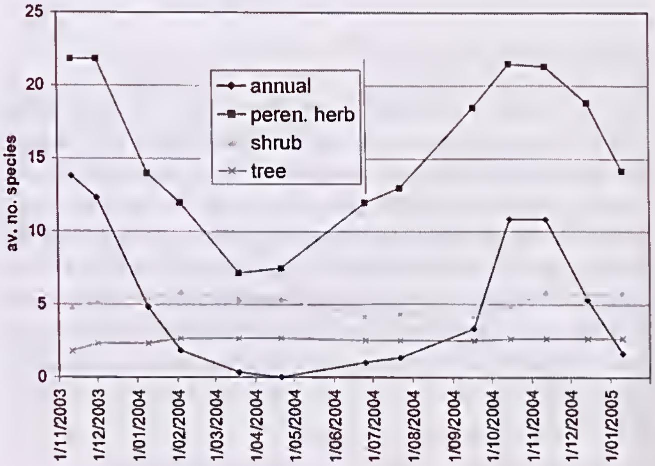

Fig. 5. Average numbers of annuals, perennial herbs, shrubs and trees for 6, 10 × 10 m quadrats at the Tarcutta Hills Reserve study site over a period of 15 months.

species were introduced (Tables 2,5), and species composition remained relatively stable from August to October (Tables 3,4). At the cooler and wetter Tarcutta Hills there was a more extended period (October to early December) when a high proportion of species were recorded (Fig. 4). The 1996 study, based on surveys in August, September, October and November, found that October assessments recorded the highest number and proportion of species, but if only a single survey was conducted in this period then only about 65–75% of the total species present at a site would have been recorded (Table 4). Likewise, in the CSU and Tarcutta Hills studies optimally timed surveys only recorded 60–70% of the species present (Figs 3,4). In the 2001–2002 study, for July to September 2001 and the 7 months from December 2001 to June 2002 less than 50% of the total species were recorded (Fig. 3). In the 2003/2005 study less than 50% of recorded species were detected from January to September (Fig. 4).

The seasonality of the various growth forms was examined for the Tarcutta Hills site (Fig. 5). The shrubs and trees were consistently recorded throughout the year. The annuals displayed a distinct seasonal trend and were recorded in very low numbers during late summer and a very dry autumn. The herbaceous perennials showed a similar yearly trend to the annuals, but only dropped to about 33% of their late spring numbers. In late autumn and winter it appeared that the herbaceous perennials resprouted earlier than the annuals began to germinate (Fig. 5). Given that the annuals were largely (68%) weeds and the herbaceous perennials were largely (93%) native (Table 2) there would be no great difference in optimal survey time if exotics or weeds were being specifically targeted.

The drought conditions of 2002 meant that a peak in species recordings did not occur in October at the CSU study site (Fig. 3). In 2003, after several months of above average or close to average rainfall (except for September), the site was surveyed again in early and mid October. Results were similar to October 2001 with 68% and 81% of total species recorded.

The Lake Cowal survey was based on two assessments in 1997 of 41 quadrats. The September and October assessments recorded, on average, 20 and 25 species respectively (Table 3). When the recordings of these two assessments were combined an average of 31 species per quadrat was found (Table 5), or expressed another way, on average, the first assessment missed 11 species per quadrat that were found in the second assessment and the second missed 6 species found in the first. This illustrates the advantages of multiple assessments and the rapid change in the detection of some species as the growing season progresses.

Relative species diversity

A wide range in the average number of species per quadrat (23–66) was recorded at the various sites (Table 5). An even wider range (6–50) was recorded for the average number of native species recorded per quadrat at the various sites (Table 5). Several sites had an average of over 50 species per quadrat and 15 quadrats had over 60 species. A relatively high species diversity was recorded in most quadrats when assessed several times between August and November or over a full year (Table 5), even though there was often lower apparent species diversity in these quadrats between December to June/July (Figs 3,4).

Table 2. Growth form information for the study sites.

A: percentages of various growth forms (annuals/biennials, herbaceous perennials, shrubs, trees). B: the percentage of native species for the growth form.

Site	Annual/ biennial		Herbaceous perennial		Shrub		Tree	
	A	B	A	B	A	B	A	B
Kindra	47	36	48	94	4	100	1	100
Ganmain	41	43	47	90	11	92	1	100
Lester	56	31	39	92	2	100	3	100
Matong	53	36	41	89	4	100	2	100
Malebo E	70	22	28	86	1	100	1	100
Matong E	67	26	27	89	3	100	3	100
ARI	75	18	23	85	2	100	0	–
Lake Cowal	53	43	40	96	5	100	2	100
Wagga 2001–3	42	25	55	88	3	100	0	–
Tarcutta Hills 2003–5	30	32	53	93	13	100	4	100
Average	**53**	**31**	**40**	**90**	**5**	**99**	**2**	**100**

Table 3. Average numbers of plant species for 10 × 10 m quadrats (with Standard Error) recorded at various sites in the SWS and CWS during August to November. The month columns record the average number of species recorded per quadrat at a site for that month.

Site	August	September	October	November
Kindra	28 (1.1)	33 (0.9)	42 (1.1)	21 (1.3)
Ganmain	28 (1.0)	27 (1.1)	32 (1.2)	16 (0.6)
Lester	19 (1.2)	27 (1.3)	34 (1.5)	18 (0.8)
Matong	22 (1.0)	28 (1.1)	35 (1.7)	19 (1.3)
Malebo E	17 (1.6)	20 (1.8)	23 (2.0)	10 (1.1)
Matong E	14 (0.6)	21 (0.9)	22 (1.4)	11 (0.6)
ARI	15 (0.5)	15 (0.5)	15 (0.6)	07 (0.6)
Lake Cowal		20 (1.4)	25 (1.6)	

Table 4. Average percentage of the total plant species recorded in quadrats (with Standard Error) at various sites in the SWS and CWS during August to November. The month averages are based on the number of species recorded in a quadrat at an assessment in relation to the total number of species recorded for that quadrat.

Site	August	September	October	November
Kindra	51 (1.4)	60 (2.1)	77 (1.3)	39 (1.8)
Ganmain	64 (1.6)	61 (1.0)	72 (1.3)	37 (1.6)
Lester	39 (1.6)	55 (1.5)	69 (1.6)	37 (1.5)
Matong	43 (2.2)	54 (1.6)	67 (2.4)	36 (1.6)
Malebo E	53 (2.3)	63 (2.4)	70 (2.2)	30 (2.8)
Matong E	44 (1.7)	65 (1.9)	66 (2.3)	35 (1.8)
ARI	65 (2.4)	68 (1.8)	64 (2.4)	32 (2.9)
Lake Cowal		64 (1.8)	81 (1.3)	

Table 5. Average numbers and ranges of overall and native species diversity at the survey sites. (Averages followed by Standard Error).

Site	Av. no. spp./quad	Range: no. spp./quad	Av. no. native spp./quad	Range: no. native spp./quad
Kindra	55 (1.5)	43–67	39 (1.5)	25–46
Ganmain	44 (1.5)	34–55	36 (1.4)	27–43
Lester	50 (1.6)	34–57	28 (2.1)	14–45
Matong	52 (2.2)	35–66	32 (1.5)	20–40
Malebo E	33 (2.8)	11–52	12 (1.3)	2–22
Matong E	33 (1.4)	24–44	15 (0.8)	11–20
ARI	23 (1.0)	16–29	6 (0.6)	3–10
Lake Cowal	31 (2.0)	9–56	16 (1.4)	1–34
Wagga 2001–3	37 (1.6)	34–41	23 (1.3)	20–27
Tarcutta Hills	66 (2.3)	59–71	50 (1.1)	48–54

Discussion

Few, if any, guidelines are available regarding optimal vegetation sampling times in south eastern Australia. Groves (1965), working in a *Themeda* grassland 15 km west of Melbourne (annual rainfall c. 520 mm), recorded flowering patterns of 101 species (37 introduced) on a monthly basis from October 1962 to January 1964. Groves recorded a distinct peak in flowering in October for introduced species and October/November for native species. Of the studied species, approximately 83% and 70% were recorded as flowering in October and November respectively, while in all other months less than 35% of species were in flower. Assuming that Groves' flowering records are equivalent to the presence/absence records of the present study, then the results of the two studies are very similar.

For the years 1949–1953 Williams (1961) made monthly notes on the vegetative and reproductive status of about 60 species in an ungrazed *Danthonia caespitosa* grassland, near Deniliquin (c. 220 km W of Wagga Wagga, average annual rainfall c. 400 mm). His results show that almost all species with a single bloom period per year flowered in September or October. The results also indicate that many species show a distinct variability in the timing and length of flowering, both year to year and within a year. This indicates that it is difficult to stipulate a single optimal time of sampling.

Morgan (1999), working in grasslands in 'western Victoria', described the regeneration of perennial species after annual summer fires. In a similar pattern to the present study his results show a peak in species richness in October, followed by a rapid decline as plants died back to their protected basal buds.

The site assessments and overall experimental design used in this study were not specifically aimed to determine an optimal sampling time in the SWS; however a wide diversity of quadrats were subject to multiple sampling, all quadrats were of equal size, and the same assessor was involved in all sampling and species identifications. Some limitations of the study are: (i) the different sites were surveyed in different years and thus different climatic conditions, (ii) not all surveys extended across a full year and different numbers of assessments were carried out at the various sites, (iii) sampling was not always at equal intervals, (iv) some surveying was conducted in drought conditions, and (v) quadrat layout differed from random to linear transect.

Some useful observations for woodland vegetation in the SWS can be made: (i) mid to late spring is probably the best time to survey to record the greatest number of plant species, (ii) there are several months of the year (December or January to July or August) where a single assessment will probably record less than 50% of the species at the site, (iii) a single assessment, even at the optimal time of year, will only record about 60–75% of the species at a site, and (iv) multiple assessments through time are needed to record a higher percentage of the plant species diversity.

While surveys conducted in mid to late spring to early summer have given the highest recordings of plant species richness, the timing of a survey within this broad period will probably be influenced by factors such as: (i) whether the survey is conducted in early, mid or late in this period, (ii) the preceding weather conditions, especially rainfall, (iii) the location of the site, east to west, within the SWS, and (iv) the vegetation at the site. Rainfall is probably the most important variable influencing plant diversity recordings in the SWS. Rainfall in the SWS is highly variable on a yearly and monthly basis (Anon. 2003, Table 1). Any recommended or stipulated optimal time for a single diversity assessment should be implemented with an appreciation of the interaction between rainfall and detection of species diversity. The results of flora surveys in the SWS should be accompanied by rainfall data for at least the previous 2 to 3 months for the site or the surrounding area and an indication of how this compares to the long-term average. This information will allow an informed assessment of plant diversity survey data. The unusually wet and cool conditions of February 2002 led to an increase in the number of species recorded (Fig. 3), while below average rainfall during the 2002 growth period led to a much reduced number of species recordings (Fig. 3). These findings would be difficult to interpret without rainfall data. Austin et al. (1981), in a study extending from 1949 to 1968 and based at Deniliquin (c. 220 km west of Wagga Wagga), showed that differences in seasonal climatic conditions have an important bearing on vegetation dynamics between years, as well as within a year.

Autumn surveys, commissioned by both private companies and government agencies, are relatively common in the SWS (pers. ob.). This may be related to stable, moderate weather conditions, a lack of appreciation of growth patterns, and/or the requirement to use allocated funding by the end of the financial year. If such studies are considered essential, then their limitations should be clearly expressed. Goodfellow and Peterken (1981), working in British woodlands, employed correction factors. They increased the number of species recorded by 10% for each of the following: (i) woodland visited once only and no previous records available, or (ii) woodland assessed outside the main growth period. Similar correction factors are unlikely to be useful in the SWS owing to the high rainfall variability, especially during summer and autumn (Table 1).

Trémont (1995) noted that native forbs make a major contribution to species richness in temperate grassy communities and provided phenological information for six native forbs (3 annual, 3 perennial) over a 17 month period. Her study showed distinct seasonal differences in processes such as vegetative growth, flowering and senescence between these species. These differences then influence whether a species would be recorded at various times of the year.

Twenty two rare or threatened plant species are listed for the SWS (Burrows 1998). Of these 4 (18%) are annuals, 16 (73%) perennial herbs and 2 (9%) shrubs. Thus about 90% of the plant species for which there are specific legislative responsibilities will probably only be recordable during mid to late-spring and/or early summer in years with near average or above average rainfall throughout the growing season. Flora surveys for environmental impact assessments should be conducted in mid to late spring, both for recording maximum diversity and optimising the likelihood of recording rare or threatened species. Surveys for threatened species should target those seasons (and years) where the species is likely to be observable above ground.

The results of this study indicate that surveys in mid to late spring will record the highest percentage of the plant species present at a site in the SWS of NSW. A single, optimally-timed survey, conducted after near- or above-average rainfall in the two or three months preceding the survey, will record about 65–75% of the species present. For much of summer, autumn and early winter a single survey or even multiple surveys will record less than 50% of the species present.

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Volume 8(4): 409–520 2004

Native riparian vegetation in Tasmania 409
E.A. Daley and J.B. Kirkpatrick

Population decline and potential for local extinction in a population of *Pultenaea glabra* (Fabaceae) in Victoria 431
Matthew Fraser, Dianne Simmons and Robyn Adams

Progress in the recovery of the flora of treeless subalpine vegetation in Kosciuszko National Park after the 2003 fires 439
Neville G. Walsh and Keith L. McDougall

Vegetation of Basket Swamp National Park, Northern Tablelands, New South Wales 453
John T. Hunter

Using environmental variables and multivariate analysis to delineate preferred habitat for *Cryptostylis hunteriana*, the Leafless Tongue Orchid in the Shoalhaven Local Government Area, NSW 467
Stephen Clark, Claire deLacey and Steven Chamberlain

Distribution and habitat of the vulnerable tree species, *Angophora inopina* (Myrtaceae), on the Central Coast of New South Wales 477
Stephen A.J. Bell

Bryophyte composition in a native grassland community subjected to different long-term fire regimes 485
John W. Morgan

Conservation issues for the vascular flora of Lord Howe Island 490
Tony D. Auld and Ian Hutton

Floristic communities of the lower Dawson River plains, mid-eastern Queensland 501
Alexander B. Pollock, Don W. Butler and Robert J. Price

The importance of seasonality in the timing of flora surveys in the South and Central Western Slopes of New South Wales 514
G.E. Burrows